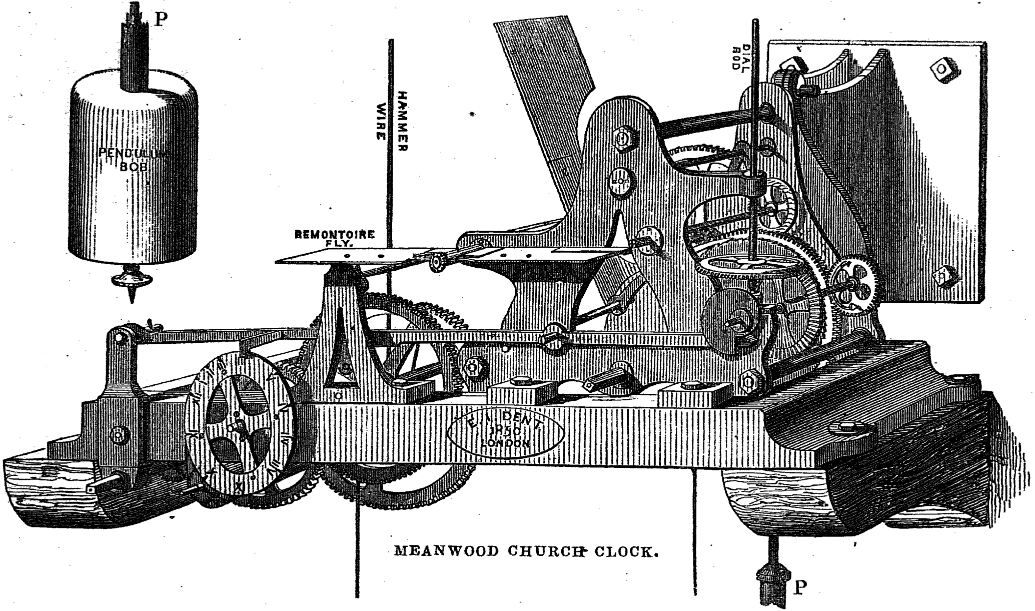

MEANWOOD CHURCH CLOCK.

A

RUDIMENTARY TREATISE

ON

CLOCK AND WATCH MAKING:

WITH A CHAPTER ON

CHURCH CLOCKS;

AND AN ACCOUNT OF THE PROCEEDINGS RESPECTING THE GREAT WESTMINSTER CLOCK.

With numerous Drawings.

BY

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AUTHOR OF TWO PAPERS ON CLOCK ESCAPEMENTS IN THE CAMBRIDGE PHILOSOPHICAL TRANSACTIONS.

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ERRATA.

Page 11, line 5, after *for* read *the day before.*

„ 19, „ 5, for *first* read *innermost,* and for *make* read *mark.*

„ — „ 6, for s_1 read s_3.

„ 76, „ 3, for $\frac{a}{c}$ read $\frac{a^2}{c^2}$.

„ — „ 5, for $\frac{W h}{a^2}$ read $\frac{W h}{c^2}$.

„ 77, „ 5, for *lose* read *gain.*

„ 92, „ 7 from bottom, for *grove* read *groove.*

„ 132, „ 9, after *that* insert *on.*

„ 169, „ 5 from bottom, for *is the only one,* read *and the Camberwell church clock, also by Mr. Dent, are the only ones.*

“ 202, „ 3, after *dial* insert *and one-fifth of the radius is large enough.*

„ 224, „ 4 from end, for *required* read *requisite.*

„ 225, „ 7, for *peel* read *peal.*

„ 250, „ 5, for *it* read *they.*

PREFACE.

I have several times been asked if there was any book on clock making, which, without being encumbered with professional details, would enable a person having a moderate knowledge of mechanical principles to understand the construction of clocks, and the things which chiefly require attention in their making and management. I believe there is no such book. Perhaps the articles in some of the Encyclopædias might partly answer the purpose; but they are neither accessible to the great majority of readers, nor do they contain some information which may be expected in a rudimentary treatise, though they do contain interesting accounts of some curious inventions, which would be out of place in a merely practical book such as this professes to be.

On the subject of church, or turret, or public clocks especially, there is almost a complete absence of literature. And yet this is just the branch of the art on which, I am sure, from what I have seen of such clocks, some general information is most needed, not only by the public who have to pay for them, but, I presume to say also, by many of the clockmakers who undertake to construct them. Common house clocks, like watches, have become merely an article of commerce; and the only problem is how to make them to sell. Astronomical clocks or *regulators,* on the other hand, are only made by the best makers, and the attention of scientific men, both professional clockmakers and others, has been chiefly directed to their improvement; and when it is stated that a good clock of this kind can be depended on to one or two seconds in a week, it will be admitted that that attention has not been fruitless. But with church and turret clocks the case is quite otherwise. They have been regarded merely as common clocks on a large and coarse scale, and it has therefore been almost taken for granted that one clockmaker could make them as well as another. Whereas in fact their largeness and heaviness is just the thing that makes them difficult to make well: *a clock,* at least the time-keeping part of it, *being the only machine whose sole business is to overcome its own friction;* and there is greater room for difference in their construction and value than in any other kind of clocks.

The quantities with which we are concerned in estimating the effects of escapements and their friction upon clock pendulums are so small, and the operation of friction itself is so entirely empirical, that really good clocks can never be made without such a combination of mathematical and practical knowledge as of course few clockmakers can be expected to possess. I hope that this treatise may occasionally be serviceable to them in this respect; and with the view of making it more so I have not scrupled, wherever any practical results depended on it, to put down mathematical results in their most general form, although in several instances the investigations, by which very simple results are obtained, are too complicated for any attempt even to indicate the nature of them in a rudimentary treatise such as this: I refer especially to the method of calculating the disturbances of pendulums, given by the present Astronomer Royal in a paper in the 'Cambridge Philosophical Transactions,' vol. III., of which the substance may be seen in 'Pratt's Mechanics.' I may add that it is no detraction from the value of those calculations and the formulæ obtained by them, that they afford the means of arriving at some practical conclusions respecting the capabilities and the relative merits of the several classes of escapements different from those which were stated by Mr. Airy himself, and which I have accordingly not thought it necessary to mention.

I have also to express my obligations to two eminent clockmakers, Mr. Dent and Mr. Vulliamy, for much practical information which they have readily communicated to me for the purpose of rendering this little book more valuable, both to professional and general readers. I must add that it is due to Mr. Dent's enterprise and determination to find out the best way of doing everything connected with his art, that I am able to state the actual results of some experiments (of course expensive in the first instance) which he ventured to try at my suggestion in the two church clocks I have several times referred to.

From the interest which the subject of the Great Clock for the new Palace at Westminster excited in both Houses of Parliament three years ago, as well as from the many questions and observations I have since heard about it, I believe that the short account which I have given of the proceedings respecting it up to the present time will be acceptable to many readers. Whether that clock is ever really to be made is a question which requires some other science than that of horology to predict. The government pledged itself to the undertaking by the commission which it gave to Mr. Barry (at his own recommendation) six years ago, as well as by the repeated assurances of the past and present First Lords of the Woods and Forests, that 'all the resources of science were to be employed upon the Great Clock.' But from the time when Lord Morpeth gave that answer until now, nothing whatever has been done in the matter. I understand that there are always turret clocks exhibited at the French Expositions; and as this is intended, we are told, to be the best and largest clock in the world, nothing could be a more appropriate subject for exhibition, and for reward if made as it ought to be, at the first exposition of manufactures for the world, than such a clock; to say nothing of the real want of it as an accurate public 'regulator,' accessible to everybody in London, either by sound or sight.

Perhaps I ought to apologise for occasionally expressing opinions of my own in a manner which may appear unusual in treatises of this kind. But several of the subjects I have had to treat of are so much more matters of opinion as to the balance of different advantages, than of demonstration or of fact, that the reader would have had much greater reason to complain, if I had merely stated just as much as is ascertained, without giving him any assistance on more doubtful matters; and of course I cannot pretend to think that, if I am qualified to write a treatise on clock-making at all, my opinion on such matters is not worth stating.

I hope especially that the suggestions I have offered for the assistance of churchwardens and others who want public clocks, may occasionally cause a good clock, instead of a bad one, to be obtained for the money they have to spend. If the book effects this, or any other of the objects I have referred to, I shall be satisfied that my friend Colonel Reid's recommendation to the publisher, of this addition to the series originally suggested by him when Governor of Barbadoes, has not been misplaced.

E. B. D.

42, Queen Anne Street, London:
1, Jan., 1850.

INTRODUCTION:

ON THE MEASURES OF TIME.

1. Before we examine the construction of instruments to measure time, it will be as well to understand clearly what it is that we want to measure.

A rod of a certain length is called a yard, and is our standard of length; but it might just as well have been any other length. There is no such thing as a natural yard, which we are quite sure whenever we meet with it is the thing we call a yard, and with which we intend our standard to agree. It is purely arbitrary, like a pound or a gallon. And it is not everybody who knows that if all our yard-wands and other measures were burnt, they could only be restored by the recollection that they bore a certain proportion, only expressible in a long number of figures, to the length of a pendulum that will vibrate a certain number of times, in a certain latitude, and at a certain temperature, during one revolution of the earth.

This revolution of the earth upon its axis is the only natural measure or standard of our time. But it is not what is commonly called a Day, which is generally understood to be the time between two successive noons or midnights. But even this is not the day of twenty-four hours by the clock, consisting of so many minutes and seconds. Let us see then what a day really is.

2. If you fix a telescope on an axis, so that it can only move in the north and south plane, and observe the time of any fixed star passing the middle of the telescope, that is the meridian of the place, twice; that time is the exact period of the earth's actual revolution, without reference to the sun or any other body, and is what we call a *sidereal day*,[*] and is always the same; and this kind of day, with its subdivisions of sidereal hours and minutes, is used for many astronomical purposes, and occasionally for correcting the artificial time shown by ordinary clocks.

3. But if the telescope (which when so mounted is called a transit instrument) is directed to the sun, instead

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[*] This is not strictly true, for sidereal time is really measured from the transit over the meridian of a certain imaginary point or line, which is the intersection of the equator and the ecliptic, and is called the first point of Aries ♈: and this point has a very slow *precession*, amounting to $50''$ in a year; which, the reader may be reminded, is a very different thing from 50 seconds *of time*, being in fact equivalent to 3⅓ seconds of time.

of a star, it will be found that the sun takes 3m. 56·5554s. of sidereal time longer, on the average, to pass a second time than a star does. The reason is that the earth has been moving in its orbit in the same direction as it turns upon its axis, and therefore, before the same place on the earth can again look full at the sun, or have the sun on its meridian, the earth must turn rather more than once round. The time of this passage of the sun is called a *solar day*, and it is evident that in the year there must be one less solar day than there are sidereal.

4. I said the solar day was longer than the sidereal by 3m. 56½s. *on the average*. For it will be found on accurate observation that this difference is variable. About the 10th of February, the 14th of May, the 25th of July, and the 2nd of November, the difference between a solar day and a sidereal one will be very nearly constant for several days; but in the middle of April and June it will vary from day to day about 11 seconds; and at the beginning of September and at Christmas, as much as 20 and 30 seconds; and in February and November these variations have accumulated to so much that the sun appears to be on the above-mentioned day in February 14 minutes too slow, and in November 16 minutes too fast; and about one-third as much respectively in July and May. This variation in the length of the solar day is caused by the elliptical form of the earth's orbit. However in a treatise on clocks we are

only concerned with the fact, not the explanation of it, for which astronomical books must be consulted.

5. Since the sidereal day does not suit our ideas of day and night corresponding to light and darkness, and the solar day is of variable length, a third kind of artificial and uniform day has become necessary, now that all the time of the world is measured by clocks instead of sun-dials. The day which is so used is that which is always the 3m. 56·5554s. of sidereal time longer than a sidereal day; and this artificial day is called a *mean solar day*, or more shortly, a *mean day;* and the time shown by clocks is accordingly called *mean time.** And the difference between mean time and the time shown by a sun-dial or any other solar instrument is called the *equation of time*, which as we have seen is sometimes as much as fourteen and sixteen minutes. The equation of time is not quite the same for the same day, in any two successive years, on account of the leap-years, but it differs so little that a table to the nearest second for every day in the year 1850, will be sufficient for all ordinary purposes, and I have accordingly given a table over the next leaf, that it may all appear at one view, of the time which ought to be shown by the clock when the

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* The *astronomical* mean day is not reckoned from midnight, as the common or *civil* day is, but from the following noon, and has no 'A.M.' Thus 11 A.M. May 1 'civil reckoning' is, in 'astronomical reckoning,' 23h. April 30.

sun is on the meridian, which is a very convenient form of the table for common use, as it saves all calculation. In using the table to examine the going of a clock between any two days before and after a 29th of February, you must use the correction given in the table for the latter of the two given days.

I take this opportunity of inserting a short table of the difference between Greenwich time and the local time of a few considerable places :—

SLOW.	M.	S.	FAST.	M.	S.
Birmingham	7	33	Cambridge..................	0	28
Chester	11	32	Colchester	3	32
Dublin	25	22	Dover	5	16
Edinburgh..................	12	43	Norwich	5	12
Exeter	14	18	Boston	0	
Glasgow	17		Grimsby	0	
Hull	1	8	Louth	0	
Leeds	6	4	Paris........................	9	21
Liverpool	11	58	Rome	40	54
Manchester	9		Vienna	65	32
Newcastle	6	24	Petersburg	121	1
Oxford	5		Constantinople	115	40
Portsmouth	4	24	Frankfort	34	
York	4	24	Berlin	53	35
St. James's, Piccadilly ...		32	Geneva	24	37

TABLE FOR TH

Showing the Time which a Clock should indicate when the Su

Day of Month	January.			February.			March.			April.			May.			June.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	0	3	51	0	13	54	0	12	36	0	3	59	11	56	57	11	57	25
2		4	19		14	1		12	24		3	41		56	50		57	34
3		4	47		14	8		12	12		3	23		56	43		57	44
4		5	14		14	14		11	58		3	5		56	36		57	54
5		5	41		14	19		11	45		2	47		56	30		58	4
6		6	8		14	23		11	31		2	29		56	25		58	14
7		6	34		14	26		11	16		2	12		56	21		58	25
8		7	0		14	29		11	2		1	55		56	17		58	36
9		7	25		14	31		10	46		1	38		56	13		58	48
10		7	50		14	32		10	31		1	22		56	10		59	0
11		8	13		14	32		10	15		1	5		56	8		59	12
12		8	37		14	32		9	59		0	49		56	7		59	24
13		9	0		14	31		9	42		0	34		56	5		59	36
14		9	22		14	29		9	26		0	18		56	5		59	49
15		9	44		14	26		9	9		0	3		56	5	0	0	1
16		10	5		14	23		8	52	11	59	48		56	5		0	14
17		10	25		14	18		8	34		59	34		56	7		0	27
18		10	44		14	13		8	16		59	20		56	8		0	40
19		11	3		14	8		7	59		59	6		56	10		0	53
20		11	21		14	2		7	41		58	53		56	13		1	6
21		11	38		13	55		7	22		58	40		56	16		1	19
22		11	54		13	47		7	4		58	28		56	20		1	32
23		12	10		13	39		6	46		58	16		56	24		1	44
24		12	25		13	30		6	27		58	4		56	29		1	57
25		12	39		13	20		6	9		57	53		56	35		2	10
26		12	52		13	10		5	50		57	42		56	40		2	22
27		13	4		12	59		5	31		57	32		56	47		2	35
28		13	16		12	48		5	13		57	23		56	54		2	47
29		13	26					4	54		57	14		57	1		2	59
30		13	36					4	36		57	5		57	9		3	11
31		13	45					4	17					57	17			

EQUATION OF TIME:

is on the meridian, for every Day in the Year 1850. (*See* § 5.)

Day of Month	July.			August.			September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	0	3	23	0	6	0	11	59	54	11	49	43	11	43	44	11	49	13
2		3	35		5	57		59	35		49	24		43	43		49	36
3		3	46		5	53		59	16		49	6		43	43		50	0
4		3	57		5	48		58	57		48	48		43	44		50	24
5		4	8		5	42		58	37		48	30		43	45		50	49
6		4	18		5	36		58	18		48	12		43	48		51	14
7		4	28		5	30		57	58		47	55		43	51		51	40
8		4	38		5	23		57	38		47	38		43	55		52	6
9		4	47		5	15		57	17		47	22		44	0		52	33
10		4	56		5	7		56	57		47	6		44	5		53	0
11		5	4		4	58		56	36		46	51		44	12		53	28
12		5	12		4	48		56	15		46	36		44	19		53	56
13		5	20		4	38		55	54		46	21		44	27		54	24
14		5	27		4	28		55	33		46	7		44	36		54	53
15		5	34		4	16		55	12		45	54		44	46		55	22
16		5	40		4	5		54	51		45	41		44	57		55	51
17		5	45		3	52		54	30		45	29		45	8		56	20
18		5	50		3	40		54	9		45	17		45	21		56	50
19		5	55		3	26		53	48		45	6		45	34		57	19
20		5	59			12		53	26		44	55		45	48		57	49
21		6	2		2	58		53	5		44	45		46	2		58	19
22		6	5		2	43		52	44		44	36		46	18		58	48
23		6	7		2	28		52	23		44	27		46	34		59	18
24		6	9		2	12		52	3		44	20		46	52		59	48
25		6	10		1	56		51	42		44	13		47	10	0	0	18
26		6	10		1	40		51	22		44	6		47	28		0	48
27		6	10		1	23		51	2		44	1		47	48		1	18
28		6	9		1	6		50	42		43	56		48	8		1	47
29		6	8		0	48		50	22		43	52		48	29		2	17
30		6	6		0	31		50	2		43	48		48	51		2	46
31		6	4		0	12					43	46					3	15

6. There is however an easy method of testing the going of a clock from sidereal observations, without any reference to the equation of time. Any person of ordinary understanding and dexterity may construct a transit instrument, sufficiently exact for this purpose, out of a vertical slit or mark in a fixed window, and the edge of a chimney, provided it is upright, and the slit so placed as to be in the meridian of the chimney edge. But it will naturally be asked how is the slit to be made in the meridian. For chimney astronomy the following method will be sufficiently accurate. Fix upon a vertical edge of a chimney on the south of some window. Determine first of all, by seeing where the shadow of the sun falls at solar noon, or thereabouts, which pane will be the proper one for the purpose, and get the clock set as nearly as you can to the right time, either by tradition from some person who possesses the true time, or from an accurate sun dial. Find in any almanac which gives such things the time of *southing*, or passing of the meridian, of any known star or planet which happens to be visible at a convenient time (allowing for your longitude, if any, from Greenwich). When the clock is near the time at which the star ought to be on the meridian, stand by the window with a sheet of tin made exactly rectangular and capable of sliding along the pane, resting on the bar of the window (supposing it to be horizontal). When the clock is exactly at the time of southing of the star, you must place the tin so that you just see the planet past the

edge of the chimney and of the tin; and there the tin must be fixed, or the glass marked and painted up to the mark.

If the edge of the chimney was its western edge, the planet will emerge from behind the chimney; and then, if the glass is painted on the western side of the vertical mark, by putting your eye nearly in a line with the mark and the chimney edge, you can enclose as fine a line of light as you please between the edge of the paint on the west side of the meridian and the body of the chimney on east side, or *vice versâ;* and that fine line of light is the line which stars have to pass when they pass the meridian. Before the mark is finally fixed, the operation ought to be performed several times, as there is sure to be some loss of time at the first trial in getting the tin to the proper place. You must observe the time of transit by listening to the number of seconds from the time when you looked at the clock.

Now when you have got this meridian line, even if it is not perfectly exact it will do very well to try the *rate* of the clock by, though not to tell the absolute sidereal time, unless it is either quite exact or you can learn how much it is wrong. To try the rate of the clock, observe the time of any well known star passing your meridian; and go and observe it again at the end of one or more sidereal days. Your clock ought to be behind its former time, at the rate of 3m. 55·9093s. of mean time for every sidereal day between the two observations.

7. Still we want to know how to ascertain the actual mean time from a sidereal observation. Now 0 or 24 o'clock by the sidereal clock of any place is, as was stated in the note to p. 8, the time of the imaginary point ♈ passing the meridian of that place. And from this point the *right ascension*, or distance along the equator (corresponding to terrestrial longitude) of all celestial bodies is measured; and it is generally expressed in almanacs in sidereal hours and minutes. Therefore in fact the R. A. of any star, given in the almanac, is the sidereal time at which it passes our meridian, since ♈ was on the meridian when the sidereal time was 0. But the mean time was 0 when the mean sun was on the meridian; therefore the R. A. of the mean sun substracted from the R. A. of the star (with twenty-four hours added if necessary) is the number of sidereal hours, &c. that have elapsed from mean noon to the time of transit of the star; and this number of sidereal hours, &c. may be converted into mean ones by multiplying them by ·99727, the ratio of a sidereal to a mean day; or if you substract 9·83 seconds from every sidereal hour and 1 second from every 6·1 minutes, it will give you the time which ought to be shown by the mean clock at the transit of the star. In some almanacs* the R. A.

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* One that rejoices in the singular name of Zadkiel's Ephemeris

of the mean sun at noon is given for every day under the head of sidereal time merely. If the R. A. of the real sun only is given, that of the mean sun is found by merely subtracting the equation of time when the clock is behind the sun, and adding it when the clock is before the sun.

8. The more obvious way however of finding the error of a clock is to observe the time when the Sun passes the meridian; and if the time then shown by the clock does not correspond with the equation of time, the clock is so much wrong. The sun is too large to be observed directly like a star at the moment of passing; but it may be observed by the same method as I have described for a star, if the times of its western edge first appearing and the other edge disappearing be observed (with the help of smoked or coloured glass, or a fog), and the bisection of them taken for the time of noon. Various kinds of meridian sun dials may be used, and no others can be very accurate on account of the refraction, nor can they be so easily made. If a narrow vertical slit is made in any thin plate facing pretty nearly south, the bright line that comes through it from the sun will always fall in the same place at noon on any surface which is level in the east and west direction, and it can be

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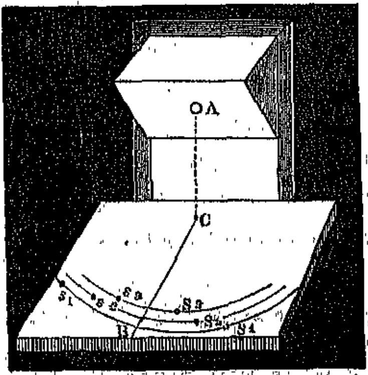
gives it, for the special purpose of saving its consulters the trouble of adding or subtracting the equation of time. It may of course be used for horological purposes without the necessity of believing in the more abstruse science for the benefit of which it is published.

observed with great accuracy. It may be convenient to describe how a meridian mark of this kind may be made without any extraneous assistance.

Make a small hole in a thin plate of painted tin or brass, set facing the south in a window-frame or other convenient place. Place a piece of slate or a smooth board quite level against the plate, and about 9 inches below the hole. I say quite level, because it is easier to make it level in every direction than to find out in the first instance which is the east and west direction. But after the meridian is found, the board may be sloped up towards the south, and the shadow will be clearer and sharper than if it is level. Moreover, the bright shadow of the hole will be clearer if the plate is bent so as to be parallel to the earth's axis; if it makes an angle of about 45° with the vertical it will do.



From A the hole in the plate drop a perpendicular A C upon the board, and make a mark at C. At a little after 11 o'clock on a fine day, observe where the image of the Sun falls on the board, and mark the place of its centre S_1, and draw a circle on the board with radius C S_1.

Observe the place of the bright spot at two other times before noon, and mark them S_2, S_3, and draw circles for them in like manner. Then, if the last observation was at 11h. 45m., go again a little before 12h. 15m., and watch for the passage of the spot over the first circle, and make the place where the centre crosses it s_1, and do the same with the other circles. Bisect the three arcs $S_1 s_1$, $S_2 s_2$, $S_3 s_3$, and if you can draw a straight line through all the bisections and the point C, that line B C is the meridian line on which the image of the sun will always fall at solar noon, and the passage of the spot can be observed nearly to a second. This therefore with the equation-table will give the means of correcting a clock on any fine day. Before the line is strongly marked it will be as well to try it both in summer and at the distance of three or four months. This apparatus is so easily made, and so useful when it is made, that every clockmaker who has not the means of obtaining the time from an observatory ought to have one, for it is no use having clocks unless you can continually recur to what may be called *the datum line*, from which they are to measure, viz., mean noon. There are many large towns in which there are literally no means of recovering the true time when it is lost except by sending somewhere else to fetch it, and there are very few people who are able to take it accurately when they see it.

9. There is besides this simple kind of meridian dial,

which anybody can make, a very beautiful little instrument invented a few years ago by J. M. Bloxam, Esq., of Lincoln's Inn, called the *dipleidoscope,* from which, *when it is once accurately fixed,* the time of solar noon can be observed with even greater accuracy, on account of the increased sharpness of the images which it produces, as well as their passing with considerable velocity.

It presents two bright images of the sun, which approach each other, and exactly coincide at noon; and thus two observations of noon are obtained, viz., the time of first contact and of final separation, the bisection of which gives the time of noon, and the time of complete coincidence. It is of no use to describe the construction of the instrument, as few persons could make it, even if they could legally do so; Mr. Bloxam has transferred the patent to Mr. Dent, who makes them, and from whom also Mr. Bloxam's pamphlet on the principles and construction of the dipleidoscope may be had, as well as the annual equation table, which is for this year that given a few pages back, to the nearest second.

10. I have no intention of inquiring into the history of the various instruments that have been used for horological purposes. Sun-dials, at least for noon, could not fail to be very early used, from the obvious fact that the shadow of any vertical body always falls in the same place at

the time when the length of the shadow was least in every day; and it would be easily observed that the intervals were very nearly equal. The sun-dial of Ahaz will occur to every one. But probably much more accurate astronomical observations than any that can be made with a sun-dial had been made long before that time by the Chaldeans, for without accurate measures of time astronomical observations can hardly be supposed to exist.

11. Everybody has heard of the clepsydras, or water-clocks of the ancients. If a vessel of water is kept full by a stream running through it, and a hole is made near the bottom, the water will run out of the hole and fill any other vessel at an uniform rate; and this other vessel may have its sides graduated, or carry a floating index pointing at a graduated plate divided into hours, and even minutes, if the index rises fast enough to distinguish them. When the index gets to the top it might be contrived so as to open a valve and let the water out, and itself go to the bottom again and shut the valve; and if this was made to take place every twelve hours it would make a self-acting clock, requiring no assistance except from the stream. If, on the other hand, a given vessel is filled and graduated according to the rate at which the water flows out, which is not uniform, but varies as the square root of the height above the hole at which it stands, this also will serve for a clock until the vessel is empty.

12. Sand running out of a hole at the bottom of a vessel however runs with very nearly uniform velocity; for on account of the friction between the particles, which does not exist in a fluid, the sand only falls out, and is not pressed out, by virtue of the same principle which enables sand to stop up a deep blasting hole, since no amount of pressure can push a considerable thickness of sand through a tube without bursting it. I have seen no account of an index fixed to an hour-glass, that is to a sand-glass; but one might be made on the plan of those toys in which sand runs into a small bucket, which turns over when it is full, moving some figure of a man or animal with it. This might be made to take place at every minute or other interval, and might move a clock-hand accordingly. Since the invention of clocks clepsydras have been made as curiosities, probably much more perfect than any that existed before. But these things now belong rather to the department of 'philosophy in sport,' than 'science in earnest,' and a description of them would be out of place in a practical treatise on clock-making.

A

RUDIMENTARY TREATISE

ON

CLOCK AND WATCH MAKING.

CHAPTER I.

ON CLOCKS.

13. A clock has sometimes been defined to be a machine for counting the vibrations of a pendulum, and so it is; but this is hardly a correct definition; for it implies firstly, that the clock has nothing to do but to count the vibrations, whereas it has also to maintain them, as a pendulum will not go on long swinging by itself; secondly, that the clock does not alter the time of vibration; which it does; and thirdly, that a pendulum or some other vibrating body is essential to a clock: which it is not; for clocks are actually made on the principle of having the velocity of their movements determined by a revolving fly, either with fans to which the air offers a resistance, or with a heavy rim, whose own *moment of inertia* prevents it from moving too rapidly. A more correct definition would be, that a clock or a watch is a machine consisting of a train of wheels turned by a weight, a spring, or any other nearly constant force, and of

which the velocity is regulated by attaching to it a pendulum, balance, or fly wheel, which always vibrates or revolves nearly in the same time. And the only distinction (except the arbitrary one of mere size) between a clock and a watch is, that a watch will go in any position, but a clock only in one.

14. The invention of clocks with wheels is ascribed to Pacificus, Archdeacon of Verona, in the ninth century. Clocks (without water) are said to have been set up in churches towards the end of the twelfth century; and there is a story of a clock being erected in Westminster Hall in 1298, out of a fine levied on a lord chief justice; and near the same time a clock is said to have been put up in Canterbury Cathedral, and one in Wells Cathedral in 1325. Mention is also made of a clock, apparently of some new construction, invented by Robert Wallingford, Abbot of St. Albans in 1326, and which was going in Henry the VIIIth's time. From these and other notices it seems pretty clear, that, though the earliest clock of which the actual construction happens to have been preserved, was that made by Henry de Wick for Charles the Vth, in 1379, yet he is not to be looked upon as the inventor of them. According to the description given of that clock, it differed in nothing, except in having a horizontal balance instead of a pendulum, from many old church clocks still in existence, being merely a thirty hour clock with one hand; and the striking part was exactly the same as is still used: in fact in some respects it exhibited a more advanced state of mechanical art than the clock (I do not know of what date) not only in existence, but in action, in Peterborough Cathedral;

which has a wooden frame instead of an iron one, and instead of being wound up by a key or winch, is wound up by long handles or spikes stuck into the barrels. It has however a pendulum. The going part of the clock has indeed lately been superseded by a modern one; which is far less creditable to the mechanical skill of the time at which it was made than the old one, especially considering that it has no dial to work, a circumstance which affords unusual facilities for a good clock. The old striking part still does the striking on a bell of considerable size.

15. From these old church clocks have descended all the modern race of smaller clocks and watches, which have arrived at a degree of perfection which seems truly wonderful, when it is considered that, though there is no such thing in nature as a perfectly isochronous pendulum (one which vibrates different arcs in the same time), and no such thing as a train of wheels with perfectly uniform action, yet pendulums can be kept vibrating with no greater deviation from isochronism than one beat in half a million. In the mean time the church clocks themselves have descended, in the hands of all but a few makers, into little better than ironmongery: and many of them display the grossest ignorance, not only of horological, but of the commonest mechanical principles. Perhaps the most striking instance of neglect of horological principles is the practice, of which Mr. Vulliamy in his 'Considerations on Public Clocks' gives several instances, of putting fans or wings to the pendulum; I suppose, for the purpose of preventing it from occasionally swinging so far as to drive the pallets into the scape wheel under the influence of such a weight

as was found necessary to carry the train through all the occasional impediments arising from bad cutting of the wheels, dirt, the force of the wind upon the hands, and all kinds of mechanical defects. It is remarkable that, until lately, the French have been much in advance of us in this largest kind of horological engineering, and have spent much larger sums upon their public clocks. Mr. Vulliamy mentions no less than four in Paris, which appear each to have cost about £1000, exclusive of some other expensive appendages, such as enamelled dials, and the bells. There is not a clock in England which has cost anything near that sum, exclusive of chimes and other appendages, which do not strictly belong to the clock. The estimates for the Great Clock for the New Palace at Westminster indeed exceed that amount; but that is to be a perfectly unique specimen, combining unusual size and unusual provisions to secure accuracy of 'performance,' as the clock making phrase is.

Of late, however, an improved style of turret-clock making has been introduced by some of the best makers. And since the erection of the clock at the Royal Exchange, which contains several contrivances never before used, there can be no doubt that, if we choose to pay for it—and less than half the cost of the above-mentioned French clocks is sufficient for all but the largest clocks—we can have large clocks made just as well as small ones. The present astronomer royal (who certainly cannot be accused of undue partiality to his own countrymen in matters of science) has said that he has no doubt that the Exchange clock is 'the best public clock in the world,' and that he 'believes it is superior to most astronomical clocks in the steadiness of its rate.'* Of course this degree of accuracy cannot be expected in any but the very best clocks; but by merely attending to a few simple considerations they may certainly be made, and without any great addition to their cost, to approach to the accuracy of all but the most highly finished astronomical clocks or *regulators,* instead of being, as they frequently are, merely the public exponents of the time of the best clock which the man who 'looks after them' happens to possess, or of the nearest railway station clock, which is probably a small spring-clock that cost £5, and is set right when it gets as much as five minutes wrong.

16. It is evident that a fly, either with fans or weights, would, if the resistance of the air and the friction of the machinery were uniform, produce a constant velocity in a train of wheels turned by a weight hanging by a string unwound from the axis of the first wheel in the train. One would imagine therefore that this would be the earliest form of a clock, as it is the most simple, and a fan-fly was actually used in De Wick's clock, as it still is, to regulate the velocity of the striking part. Whether this was so or not, we have no means of knowing; but it is worth noticing that that construction, or a slight modification of it, is actually in use now. The clock which is used to keep the great equatoreal telescope at Cambridge in motion opposite to the motion of the earth, so that it may remain for some time pointed to a given star, and not move by jumps as it would if driven by a clock with a vibrating pendulum or

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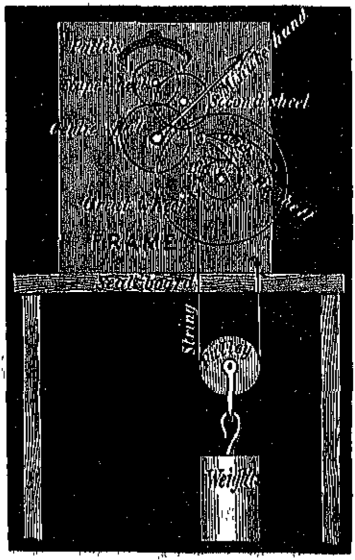
* Parliamentary Papers respecting the Great Clock for the New Palace.

balance, is regulated by a *governor*, like that of a steam engine; which is also called a *conical pendulum*, because the rod of each ball describes a cone as it revolves. As the force of the train increases the velocity of the balls they fly farther out, which increases their moment of inertia or resistance to motion, and may also be made to apply an increasing friction by means of a spring to some part of the clock, and so restrain the increasing velocity, as the governor of a steam engine regulates the supply of steam to the cylinder. Such pendulums have not yet been made to approach the accuracy of a vibrating pendulum with an escapement, being much more affected by any variation in the force of the clock. The time of one revolution of such a pendulum in a circle (which it cannot always be persuaded to describe) is the same as that of a double oscillation of a vibrating pendulum whose length is equal to the height of the point of suspension of the revolving pendulum above the plane of the circle in which the ball revolves; which will of course vary as the force that drives the pendulum varies. There are other practical difficulties in their use; and it appears to me that uniform continuous motion of a train that has heavy and therefore variable work to do is more likely to be obtained by the method which I shall describe under the head of *train remontoires* (176), than by any contrivance for regulating the motion of a conical pendulum by friction.

17. Most people know that a clock consists of a train of wheels, generally four, of which the lowest, if it is an eight day clock, turns round in about twelve hours, or requires fourteen turns to wind it up for the week, and the

highest turns in a minute. The two intermediate wheels are merely required to carry off the difference of velocity between the two extreme ones and to work the hands. The lower of these two intermediate wheels is usually made to turn once in a hour, so that the long or minute hand may be set upon its axis or *arbor* produced as far as the face of the clock; and the second wheel has nothing to do but to reduce the multiplier of sixty, or the ratio of the velocity of the highest to that of the *centre wheel,* as the one which carries the long hand is usually called. It may be convenient to give a sketch of the common arrangement of the going part of a clock, with the different parts marked, from which their action will be pretty evident.



18. The string is coiled sixteen times round the barrel when the clock is wound up. The barrel axis or arbor has a square end to fit the winding key, and when you turn it to the right the ratchett teeth, of which three or four are shown in the drawing, raise the click which is fixed to the great wheel and kept pressing against the ratchett by a spring; but when you stop winding, the ratchett teeth cannot pass the other way, and so the weight acts upon the wheel, tending

to turn it to the left. The great wheel has usually ninety-six teeth, and it drives the little wheel *or pinion* of the centre wheel, which has eight teeth *or leaves*, and therefore goes twelve times as fast as the great wheel. The centre wheel drives the pinion of the second wheel, which drives the *scape wheel*, and their teeth and leaves may be divided in any way, so that if p_1 be the number of leaves of the scape wheel pinion, p_2 of the second wheel pinion, and t_1 and t_2 the number of the teeth that drive them respectively, $\frac{t_1\, t_2}{p_1\, p_2}$ may $= 60$. The only conditions to be observed are, that no driven pinion ought to have less than seven leaves at the lowest (except of a kind which I shall mention hereafter); and that if the teeth of both wheels are of the same size, the centre wheel must have more than, or at least as many as the second, or they could not be got into the frame together. Suppose either p_1 or p_2 to have seven leaves and the other eight, then $t_1\, t_2$ must $= 60 \times 56$; and those two numbers 60 and 56 will do for the teeth of those two wheels as well as any other numbers giving the same product.

19. With regard to the weight, the reader will observe that it hangs by a double line, or a single moveable pulley, the effect of which is that only half the weight really acts upon the clock; but then the string is upon the whole double the length of the actual fall of the weight, and therefore the effect of the weight is just the same if it were hung by one string and had the same fall; in which case the barrel would of course have to be only half the size, or the number of teeth in the wheel doubled, or the number

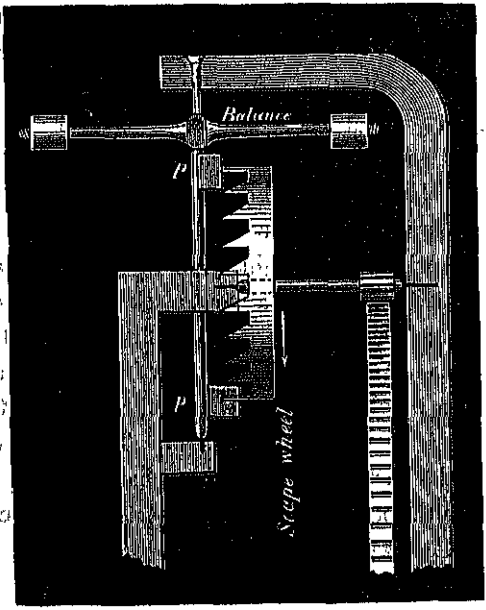
of leaves in the centre wheel pinion halved. In comparisons of clocks one sometimes sees calculations of what the weight is equivalent to 'on the single line;' or what is worse, a mere statement of the weight without any information as to its fall, which is just as necessary an ingredient in the comparison. It does not signify (except as regards the friction of the pulleys, which cannot be reduced to calculation) what the weight on the single line is, or whether there is one line or a dozen: a given weight falling a given height is equivalent to itself, and to nothing else, except another weight falling a height as much greater or less as the weight is less or greater. Therefore in every possible case if you want to see how much of the 'first power' of the clock is wasted in the friction of the train and pulleys, or how much a given escapement requires, you have nothing to do but to remove the pallets and fix to the scape wheel or its arbor an arm of any length that is convenient, and hang small weights to the end of it, till you find what weight the clock will just decidedly lift, the arm being horizontal. The arm should have a counterpoise and be as light as possible, so that its own weight may not enter into the question or add much to the friction of the scape wheel pivots. Now if you know the fall of the clock weight for eight days, you know it for one day, and one minute, or one revolution of the scape wheel, whatever it may be, or any aliquot part of that revolution; and if you know the length of your measuring rod you know that its end would move through a space 6·28 times the length of the rod in one revolution: or, without that calculation, you may turn the scape wheel through one-eighth or one-tenth of a revolution, and measure how much the little weight rises therein. Suppose this rise is *b*, and the corresponding fall of the great weight *a*; then the great weight *w* ought to be to the little weight *m* as $b : a$. It will in fact always be a great deal more, and the amount of the excess of $w a$ over $m b$ in different clocks shows the comparative loss of power in their trains.

20. And again for the converse of the experiment as regards the escapement (of which I shall treat presently) when you know what the momentum of the clock weight really amounts to by the time it reaches the scape wheel, you know how much of it is consumed in driving the train, and how much goes to drive the pendulum. These proportions will be found very different in different clocks. But it is time we should proceed to explain what that important part of a clock called the escapement is.

ESCAPEMENT.

21. An *Escapement* is a contrivance by which the teeth of a wheel, commonly called the scape wheel, are successively let go and stopped at certain short intervals of time. In all the common kinds of escapements there are two pieces of steel called *pallets* fixed to an axis which vibrates, so that as one pallet moves out of the way of the teeth, the other moves into the space between some two teeth, and so stops the wheel. Consequently as every tooth has, at some point in the revolution of the wheel to clear both pallets, there will always be twice as many beats in one revolution as there are teeth in the wheel. But the escapement must do something else: the pallets must be of

such a shape that as the teeth escape they shall give a push to the pallets, and this push is communicated to the vibrating axis, and to the pendulum or balance, which is attached to it. A balance is simply a fly wheel, and was no doubt first called a balance, because in the earliest clocks it was in the form of a balance and not of a wheel, consisting of two arms set upon a vertical axis and carrying weights hung at the ends of the arms. This was the form of the balance of De Wick's clock: afterwards the weights, instead of being hung on to the arms, were screwed on, so that their distance from the axis could be adjusted more accurately. The escapement was exactly the same as that of a bottle-jack, or the commonest kind of watch, and is called a *vertical* escapement. The pallets are two flat pieces of



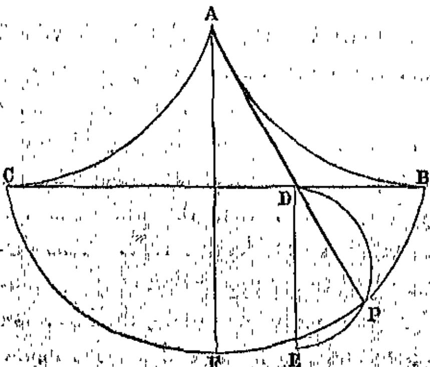
steel *p, p,* set on to a vertical axis, in planes about at right angles to each other. In this drawing the highest tooth of the wheel (which is from its shape called a crown wheel) is represented as just escaping and coming forward (or towards the reader); the lowest tooth then strikes against the lower pallet, which stops it; and not only stops it, but, as the vibration of the balance in that direction cannot be suddenly stopped, the pallet advances a little further forwards, and so brings the wheel back a little, and produces what is called the *recoil*, which is, in a less degree, communicated to the rest of the wheels, and ultimately to the weight which drives them. It is evident that each tooth as it escapes gives a push or impulse to the pallet which presents a sloping face to the direction of the tooth; and so the time of a vibration in this clock depended upon the force of the impulse relatively to the moment of inertia of the wheel, except that a greater force would cause it to make larger vibrations. The effect of such an escapement as this may be judged of by taking the pendulum off a common clock, leaving the crutch on, and observing the difference between the time the hands will take to make a revolution when the weight is in its original state and when it is added to. In a bottle jack the piece of meat and the iron wheel which is generally hung to the jack together form the balance. The jack is driven by a spring instead of a weight, and the velocity of rotation of the joint diminishes as the spring runs down. The scape wheel of the vertical escapement must either have an odd number of teeth, or the axis of the pallets must be a little on one side of the centre of the wheel.

PENDULUM.

22. Clocks remained with balances it seems for about 300 years after De Wick's time. And there was a great dispute as to the first inventor of clock pendulums. It is usually stated that the famous Galileo discovered (as he supposed) from observing the swinging of a lamp hung from the top of a church, that pendulums oscillate through different arcs in the same time: a property which is called the isochronism of the pendulum. It is said, however, in the able and interesting article on clocks in the *Encyclopædia Britannica* (last edition), that this cannot be reckoned among the discoveries of Galileo, 'for the ancient astronomers of the East employed pendulums in measuring the times of their observations, patiently counting their vibrations during the phases of an eclipse or the transit of the stars, and renewing them by a little push with the finger when they languished: and Gassendi, Riccioli, and others in more recent times followed their example.'

It is not indeed strictly true that pendulums do vibrate different arcs in the same time; but it is true, that so long as the arcs do not exceed a few degrees, the oscillations are very nearly isochronous. And, therefore, if a pendulum can be kept swinging nearly the same small arc, its oscillations will be so nearly isochronous, that the difference will not be sensible except in a considerable time. This discovery would naturally lead to the application of the pendulum to clocks: and as is usual in such cases, the invention was probably made independently by several persons about the same time. And in favour of the claim of Harris, the clockmaker, who is said to have made a pendulum clock for St. Paul's, Covent Garden, in 1621, several years before Dr. Hooke, Huygens, or Galileo's son, who all claimed the invention, it may be remarked, that if, either by accident or design, he placed a clock with the axis of the balance horizontal instead of vertical, and left one of the arms without its weight, he would see that he had made a clock with a pendulum, of which the isochronism was probably by that time generally known, and he would naturally adopt it immediately.

23. But whoever was the inventor of pendulum clocks, there is no doubt that Huygens was the discoverer of the true theory of the pendulum; and though his application of the theory to practice is now abandoned, yet as all pendulum calculations depend upon it, it is proper to give a short explanation of it. He discovered that the curve in which a body must move so as to oscillate large and small arcs in the same time is not a circle but a cycloid; which is the curve generated by a point P in the circumference of a circle D E P rolling on a straight line B C. And he also found that it has this remarkable property: that if the cycloid B P F C is



cut in two at its lowest point F, and the two halves put together as in this figure, CF being placed in the position AB, and BF in the position AC, then the end of a string AP of the same length as AB will, as it unwinds from AB and winds on to AC, redescribe the original cycloid BPFC. This is expressed mathematically by saying that both the involute and the evolute of a cycloid is an equal cycloid. Consequently if a weight or *bob* were hung on to the end of the string AP, it would be a pendulum swinging between the *cycloidal cheeks* AB, AC, and describing the cycloid BPFC; and such a pendulum would make large and small oscillations in the same time, or would be perfectly isochronous. Nevertheless it is found that the impossibility of making the cheeks so accurately as to cause the pendulum to vibrate in a true cycloid, as well as other causes, all apparently insignificant, so much disturbs the isochronism of such a pendulum, that it is more isochronous, even up to arcs of 6° or 7°, without the cycloidal cheeks than with them.

24. It will now be evident why pendulums swinging in a circle in small arcs are nearly isochronous, and more so the smaller the arcs are; for if you describe a circle with the radius AF, it will very nearly coincide with the cycloid for a short distance near F, the lowest point of the cycloid, but will deviate farther from it the farther you go from F; but the smallest arc in the circle really takes more time to oscillate than the largest in the cycloid. The difference between the time of any small arc of the circle and that of any arc of the cycloid varies nearly as the square of the circular arc, or of the angle which it represents; and agai the difference between the times of any two small and nearl

equal circular arcs varies as the arc itself; that is, if a clock pendulum is swinging 4° from zero, and from some cause the arc is diminished 5′ or 10′, the clock will gain twice as much as if it had only been swinging 2° when the same diminution took place: which is just the opposite of what would probably have been guessed. This is called the circular error, and if a is the arc, and da the decrease of it, the gain of the clock in the day (supposing it to have a seconds pendulum) is $10800\ ada =$ rather more than 1 second, if $a = 2°$ or $\cdot 035$ (the radius being unity) and $da = 10'$.

25. It is well known that a two seconds pendulum is four times as long as a one second pendulum: that is to say, the time of vibration of a pendulum varies as the square root of its length. But this does not tell us what the actual length of a seconds pendulum must be. Let l be this length, and t the time of one oscillation measured in seconds; π the ratio of the circumference of a circle to its diameter, or $3\cdot 1416$; g the force of gravity, which is expressed by the number of feet per second, or the velocity with which a body is falling at the end of one second, or twice the height that it falls in a second; then $t = \pi\sqrt{\frac{l}{g}}$. In England $g = 32\cdot 2$ feet; and therefore the length of a simple pendulum to vibrate in one second of mean time must be $39\cdot 14$ inches nearly. And in like manner the pendulum to vibrate sidereal seconds must be $39\cdot 14 \times 997^2 = 38\cdot 87$ inches (§ 7). I may mention here that a clock with a pendulum for mean time may be made to show sidereal time (though it will not mark sidereal seconds) on another dial, by the addition of four wheels

and two arbors as follows. Put a wheel of 247 teeth on the centre-wheel arbor of the clock, and let it drive a wheel of 331 teeth on an arbor which also carries a wheel of 43; and if that drives one of 32, this last wheel will serve for the centre wheel to carry the minute hand of the sidereal dial; as it will turn slower than the other centre-wheel in the ratio of sidereal to mean time within a fraction of no more than $\frac{1}{1400}$ of a second in a day.*

I spoke just now of a *simple* pendulum. A simple pendulum is, what can only exist in theory, viz., one in which the rod has no weight and the bob consists only of a single heavy point. The weight of this point or oob is of no consequence in the theory of the simple pendulum, though it is, as we shall see, of great consequence in practice in resisting the various disturbances to which a pendulum is subject. Every real pendulum however (which in mathematics is called a compound pendulum) is equivalent to some imaginary simple pendulum; and the thinner the rod is, and the heavier the bob, the more nearly the real pendulum will approach in length to a simple one of the same length, measured from the point of suspension to the centre of the bob. When the rod and the bob are of any regular shape, as they generally are in clocks, it is not very difficult to find by calculation the length of the equivalent simple pendulum, or the distance from the axis of suspension to a point in the real pendulum which would be the bob of the simple pendulum if the whole mass were collected there. This point is called the *centre of oscillation.* But it is not like the centre of gravity, a fixed and independent point, for there is a different centre of oscillation for every different centre of suspension. It cannot be explained how the centre of oscillation is found without reference to another imaginary quantity called the *radius of gyration.* If M is the whole mass of a body revolving or oscillating about any axis, and k is the radius of gyration about that axis, then $Mk^2 =$ the sum of all the elements m of the body each multiplied into the square of its distance r from the axis, which may be expressed as $S(mr^2)$; and therefore $k^2 = \frac{S(mr^2)}{M}$. This sum can only be found by means of the integral calculus in every particular case. But there is this curious property in revolving bodies; that if we have once found the radius of gyration k_1 belonging to an axis through the centre of gravity, then the k belonging to any parallel axis at the distance h from the former one is given by this equation $k^2 = k_1^2 + h^2$. Suppose then that we know what k_1 is for a body of any shape of which a vertical section in a plane perpendicular to the axis of suspension is A B C D revolving round its centre of gravity G, and we make it revolve or oscillate about a new axis through S, and we want to know what is the length S O of the equivalent simple pendulum; it may be proved

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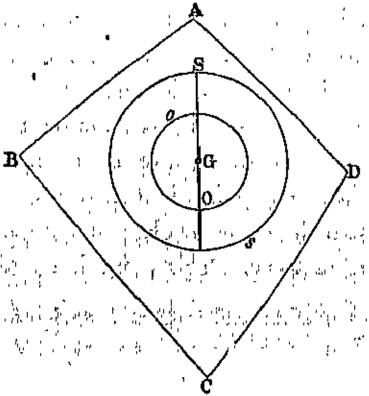
* These numbers are taken from the Philosophical Magazine for Feb. 1850.



that $S\,O = \frac{k_1^2 + S\,G^2}{S\,G}$ and $\therefore\ G\,O = S\,O - S\,G = \frac{k_1^2}{S\,G}$.

From this we may see also that if we draw two circles round G, one with the radius S G and the other with radius O G, we may put the axis of suspension anywhere in either of the two circles and still the body will oscillate in the same time. Perhaps therefore the *radius* of oscillation would be a more correct term than the *centre* of oscillation. Now since $S\,G = \frac{k_1^2}{O\,G}$ it is evident that the nearer the axis of suspension is to the centre of gravity, the farther the corresponding centre of oscillation will be; and this is the reason why a small and delicate scale-beam will oscillate as slowly as a pendulum many feet long; and it also suggests a mode in which a pendulum might be made to oscillate very slowly in a small compass. If we make a pendulum with two bobs, one above and one below the axis of suspension, or take a wheel with a heavy rim and suspend it on an axis a little out of its centre, it may vibrate two or more seconds in no greater space than a one second pendulum; but such a pendulum will not be so effectual in resisting the disturbances of the escapement as a long pendulum of the same weight, which is what we want a pendulum to do.

In all clock pendulums the effect of the weight of the rod is to throw the centre of oscillation a little above the centre of gravity of the bob, though below that of the whole pendulum; and by a few trials of the bob at different heights the pendulum can be made to vibrate in the proper time without the trouble of actual calculation. Now on looking at the drawing of the cycloid, it is easy to see that the centre of suspension of a real (*i.e.* not a simple) pendulum swinging between cycloidal cheeks is continually changing, and therefore the radius of oscillation is continually changing, and deviating from the length required to describe the cycloidal arc. In other words a real pendulum swinging in cycloidal cheeks is not equivalent to a simple pendulum swinging in a cycloid, and therefore is not isochronous.

SUSPENSION OF PENDULUM.

26. Pendulums are now almost always suspended by a short and thin spring instead of an axis, because they then swing without any friction; and they are connected with the axis or *arbor* carrying the pallets by a *fork* or *crutch*, which is a light rod or arm coming down from the pallet arbor as if it was intended to be the pendulum, but ending in a fork which embraces the pendulum rod closely but not so tightly as to prevent the rod from sliding within it; so that the pendulum and the crutch move together, and the pallet arbor vibrates as if the pendulum were hung directly to it in the old way. It is to be observed, that as the spring does not admit of being bent suddenly like a string, but assumes a curved form as the pendulum swings, its effect approaches to that of the cycloidal cheeks. It has accordingly been attempted to make the spring of such a form and strength as to render the vibrations of the pendulum isochronous; but without success; and it is of much more consequence to find the spring which requires the least possible maintaining force to keep up a given amount of vibration of the

pendulum, which is probably as thin a spring as is safe for the weight of the pendulum.

I am aware that some experiments have been published, and referred to in the article on clock-making, among the 'manufactures,' in the *Encyclopædia Metropolitana,* from which it would appear that a spring ·003 of an inch thick affected the vibrations of a pendulum of 14lbs. weight less than any other spring of the same length and width, either thicker or *thinner*. I must say I should have had some difficulty in believing that there was not some mistake in such a result, from the thinner springs having got what is called a *set* in fixing them (which is very likely to happen with very thin ones) or some other cause, even if I had not been told also that similar experiments have been made by other persons with the different and more probable result, that the thinner the spring, without limit, the less it affects the pendulum. And as springs cannot be used with safety of such thinness in proportion to the weight of the pendulum as that above mentioned, we may in any case adopt the practical conclusion that the thinner the spring is the less it will affect the pendulum; that is, the less its rate will differ from a pendulum hanging from an axis of infinitely small thickness.

27. It is of great importance that the real point of suspension of the pendulum, that is the top of the spring where it begins to bend, should be kept firmly in the same place; for if it moves it will increase the time of vibration, since this is evidently the same thing as if the fixed or real point of suspension was a little higher up, or the pendulum so much longer. For this reason, in the best clocks, the *cock* which carries the pendulum is a strong piece of brass,

or in large clocks a cast-iron frame, firmly fixed to the wall at the back of the clock. In order that the pendulum may hang so that the spring will have no tendency to twist it as it swings, the top of the spring is pinched or 'clipped' between two thick pieces of brass or iron called *chops*, and firmly screwed there; and these chops have square ends exactly at right angles to a line down the middle of the spring. A little way below the top of the chops, and exactly in the middle, a strong steel pin is put through them and the spring between them, at right angles to the plane of the spring, and this pin has shoulders, so that its thin ends beyond the shoulders will just drop into two nicks or Vs in the sides of the cock with the shoulders resting against the sides. It is evident that the effect of this will be that the weight of the pendulum will cause the square ends of the chops, and therefore the top of the spring, to be horizontal; and so, if the pendulum is made symmetrically, as of course it ought to be, it will vibrate in a vertical plane at right angles to the line which is the top of the spring, without any tendency to twist.

28. The two Vs should be made as nearly level as possible, and the clock frame must be so placed that the pallet arbor is exactly at right angles to the plane of motion of the pendulum. It will be easily seen if it is not, because then the pendulum will slide backwards and forwards in the fork by which it is connected with the pallets. In the chapter on church clocks I have given a drawing which will show the suspension of a pendulum. In common clocks, both house and turret clocks, the cock is fixed to the clock frame, and has merely a slit in it into which the spring fits,

having a piece of brass rivetted on to the top to keep it from dropping through the slit. And this slit is very often made so crooked, or oblique to the axis of the pallets, that there is considerable friction of the pendulum sliding in the fork; and the cock is generally made so slight, and the clock itself so loosely fixed to the clock case, that the motion of the pendulum may be plainly felt if you put your finger on the clock.

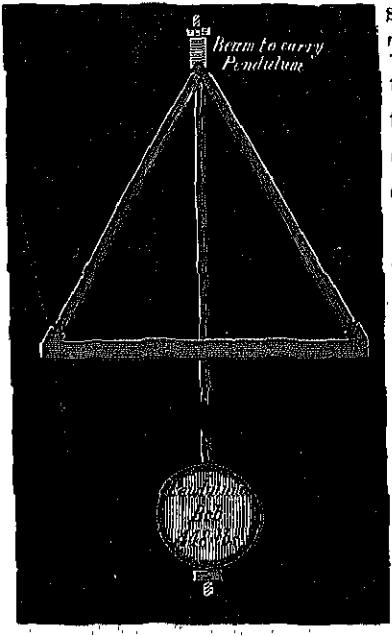
KNIFE EDGES.

29. Occasional mention may be seen in books of pendulums vibrating for several hours on *knife edges*, that is on a suspension much like that of a scale beam. Such a suspension is the best for experiments to ascertain the undisturbed time of vibration due to gravity only, excluding the elasticity of a spring; but it is not to be inferred that it will answer in practice for a permanent pendulum of the proper weight for a clock; for even if the knife edges and the planes on which they stand are made of the hardest stones, it is found that they soon suffer from the severe pressure, and introduce an amount of friction which is fatal to the accuracy of the pendulum.

FRICTION WHEELS.

30. A suspension on friction wheels has also been tried, but generally without success, the pendulum pivots always wearing a hollow in the wheels; and then of course they ceased to roll, and produced an amount of friction which was fatal to the proper action of the pendulum. Mr. Vul-

liamy, however, states in the papers respecting the Westminster clock, that the pendulum of the clock at the Post-office, which weighs 4 cwt., has been going ever since it was put up upon friction rollers; that is to say, upon so much of an entire friction wheel as is required for the small angle through which the pendulum vibrates. The arrangement is shown in this drawing. The bearing faces of these portions of friction wheels are not indeed made sensibly circular, but are flat pieces of very hard steel, with certain provisions for securing to the pivots a flat bearing which it is not necessary to describe; but as the radius of the pivots is only 1-150th of that of the friction wheels, which are 2ft. 6in. long, and the rollers only move through an angle less than 1' on each side of zero, the versed sine or measure of the curvature of a friction wheel for that angle is too small a quantity to be expressed by a table of logarithms of seven figures; and therefore for all practical purposes the bearings are the same as if they were cylindrical portions of entire friction wheels.

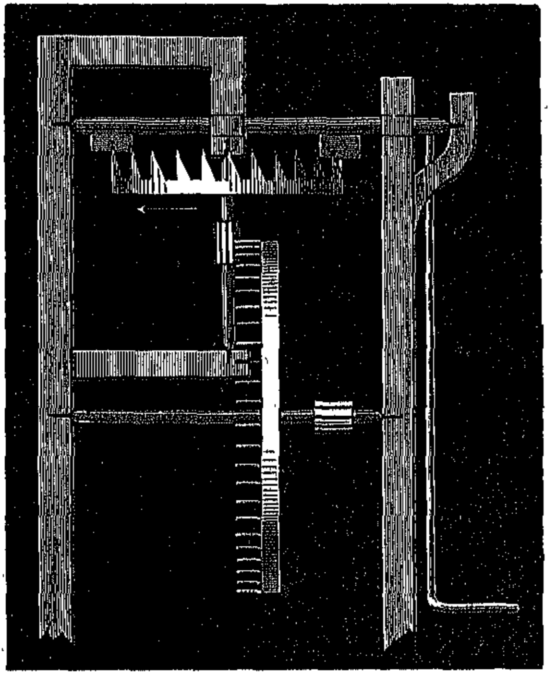


Mr. Vulliamy tells me that from the weight having been thrown almost entirely upon the pair of rollers nearest to the pendulum, and the faces having been allowed to get dirty, it has been necessary to repolish them once lately. I should be inclined however to make the pivots rather thicker than ·4 inch diameter for a very heavy pendulum; and the rollers should be placed nearer together, because the farther they are off the greater the pressure is upon them, in the inverse ratio of the cosine of half the angle included between them. It happens that for 60°, the angle at which they stand in the Post-office clock, they have to bear just 1-4th more pressure than the actual weight of the pendulum. They would act at any angle safely above that to which the pendulum swings: 20° between them would give them a sufficiently wide *stride* for a firm bearing and add hardly anything to the pressure, and would also reduce the tendency which friction wheels always have to twist the pivots. The pivots here are not indeed common projecting pivots, which would be too weak, but a hard piece of turned steel bedded into a strong beam, to which the pendulum is hung, and to another part of which the pallets are fixed.

The advantages of this method are, that there is no necessity for any compensation of the spring; which however, as will be explained under 'compensation of pendulums,' requires only a small addition (though of rather uncertain amount) to the ordinary compensation required for the expansion of the rod. The risk of a spring breaking is too rare an accident to be worth enumerating as an advantage of this suspension; and it can be repaired in an hour when it does happen. The principal advantage of it probably is that it enables the pallets to be put on the arbor which carries the pendulum, or in other words dispenses with a crutch, and therefore prevents the loss of force which must always (though to a small extent) take place in the transmission of the impulse through the crutch, both by the friction and the shake in its pivot holes; and we shall see that everything that diminishes this force, and therefore requires a stronger pressure on the pallets, increases the chances of error in the going of the clock.

No doubt even the small amount of rolling friction in this suspension would destroy the motion of a free pendulum sooner than a spring: but the proper comparison to make is between a common pendulum with a spring and crutch, and this without a crutch. I have no means of stating the result of such a comparison, either as to this point or the performance of th same clock with the two different pendulums, which should require to be tried before I would undertake t recommend such a suspension. Mr. Vulliamy however tell me that the Post-office pendulum was kept vibrating 2° 22′ with only a weight of 30 lbs. falling at the rate of 47 fee in the 8 days (the dial work being unattached); which i an unusually small weight and fall for a large clock; an I must say (with the reservation just now made) tha I think this fact is of much more importance toward determining the actual merits of the plan than th astronomer royal's inference, in his report upon the plan for the Westminster clock, that it would fail because h 'knows that it would fail for a balance or a vertical-force magnetometer:' on which it is very obvious to remark that knife edges are the only things that answer for a balance, and yet they invariably fail under the continued pressure of a heavy pendulum. I need hardly say that this suspension must be very expensive, and would require the greatest care in properly constructing and adjusting.

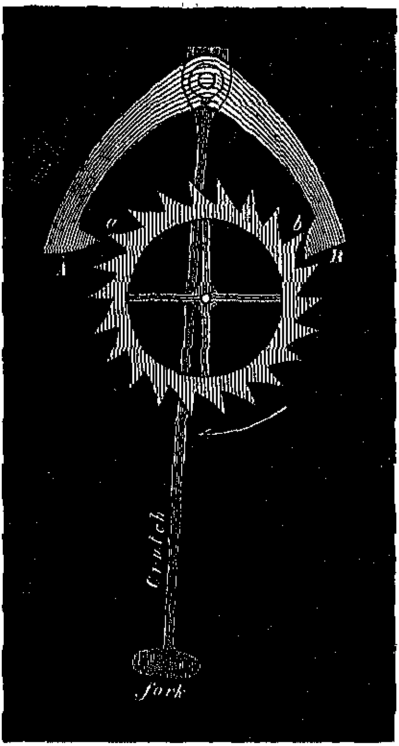
31. Long after pendulums were invented, the vertical escapement continued to be used, in the form in which I have suggested that Harris may have invented pendulum clocks; and such clocks are still in existence. The arrangement is that shown in this drawing, a second crown wheel



being used in order to keep the arbors of all the wheels except the scape wheel horizontal. A wheel of this kind is sometimes called a *contrate* wheel; and its teeth and those of the pinion which it drives ought properly to be of the shape required by two conical or bevelled wheels of the respective sizes of the wheel and pinion. In practice, however, the pinion being small is made cylindrical as usual, and the teeth of the contrate wheel being thin, they work together sufficiently well for the work in which they are employed, such as vertical watches. Clocks with this escapement however have been quite superseded by the invention of

ANCHOR PALLETS.

32. These are said to have been invented either by Dr. Hooke, one of the most scientific men, and probably the greatest inventor of the 17th century, or by Clements, a London clockmaker. It will be at once understood from this drawing what they are. [*See next page.*] The bottle-jack or 'vertical' pallets, being close to their axis of vibration, required the pendulum to move through a large arc in order to clear the teeth of the scape wheel; and besides what we have seen of the disadvantages of large arcs, they require a larger maintaining power than small ones. In this drawing a tooth *a* is represented as having just escaped from the pallet A, and a tooth *b* on the opposite side of the wheel has dropped on to the pallet B. The pendulum will not however stop here, but will advance a little further to the left, and so the slope of the pallet B will drive the tooth *b* back again a little and produce the *recoil*, which may be



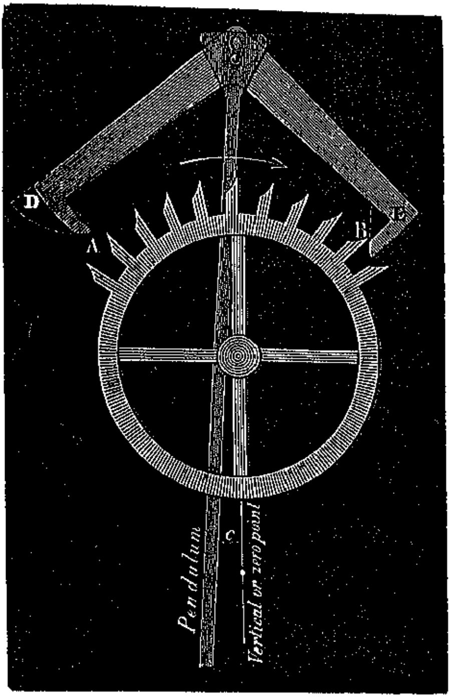
observed very plainly in any common house clock with a seconds hand. The sloped face of the pallets causes the teeth to give them an impulse in escaping, so as to maintain the motion of the pendulum. This kind of escapement is much the most common, and will probably never be superseded, as it is sufficiently accurate for ordinary purposes, and is very easy to make, since no particular form is required for the pallets.

Their acting faces are generally made flat; but they are better convex, as in the drawing, as there is then less recoil and less wearing of the pallets by the points of the teeth. Strange as it seems that brass teeth should wear holes in steel made as hard as it can be tempered, it will always be found that the teeth have worn holes in these pallets after a few years, and the hole will be deepest towards the end of the place which the tooth reaches. It is evident that the tendency to make this hole will be less if the pallet is convex than if it is flat; and accordingly in the best clocks of this construction the pallets are so made; and care should also be taken that they are so placed that the recoil and the drop may be equal from each pallet. The recoil escapement is now abandoned in all the best clocks, though it once had considerable persons as its advocates, who appear to have been misled by observing that it keeps the pendulum to the same *arc* more than the dead escapement does, and thence inferring that it would keep it more nearly to the same *time;* whereas it is now proved, both by experiment and calculation, that although, as the force of the clock diminishes from increasing friction or thickening of the oil, the arc will diminish, the clock will nevertheless lose; the loss caused by the escapement being more than enough to counterbalance the gain due to the *circular error* of the decrease of the arc. The same is the case with a watch having a *vertical* or a recoil escapement.

DEAD ESCAPEMENT.

38. The escapement which is now used in nearly all astronomical clocks and in all good turret clocks is called the *dead beat* escapement, and was invented by a clockmaker of the name of Graham in the last century. A recoil escapement would be converted into a dead escapement by making the slope of each pallet stop at the points A and B where the teeth fall, and making the rest of the pallets AD and BE portions of a circle whose centre is C the axis of the pallets. For in that case, however far the pendulum may swing no recoil can take place. The reason

why this escapement is so much better than the recoil escapement is, that a variation in the force of the clock train produces hardly any effect upon the time of oscillation of the pendulum, though it produces a considerable effect upon the extent of its oscillation.



34. This may be shown in a general way as follows. Let c be the angle which the pendulum rod makes with the vertical o when a tooth begins to act on the sloped face of the pallet, c' the angle on the other side of the vertical at which the impulse ends or the tooth escapes. Theoretically c and c' might be equal, but practically c' must be a little larger than c, in order that the tooth may not drop exactly on the corner of the pallet but just beyond it on the circular or dead part. Now while the pendulum is descending from c down to o the force of the clock acts in the same direction as gravity, which is the same thing

as if the force of gravity, or the earth's attraction, were increased by a certain amount; but while the pendulum ascends from *o* up to *c'*, gravity may be considered as diminished by the same amount (assuming the force of the clock to be constant throughout); and therefore on the whole the two disturbances would balance each other, but for the fact of *c'* being rather larger than *c*; and as the tooth evidently makes a larger angle with the pallet towards the end of the impulse than at the beginning, the force is not quite constant throughout, but a little greater through *c'* than through *c*; and therefore on the whole the force of gravity may be considered as a little diminished, and the pendulum will vibrate a little more slowly than if it were free from the clock; for it is evident that if the attraction of the earth were weaker a body would fall, or a pendulum vibrate, more slowly, as the time of the ascent is always equal to that of the descent. It is also evident that as the force acts throughout in the same direction as the pendulum is going, it must increase the arc of vibration.

35. Moreover the uniform friction on the dead part of the pallets hardly affects the time directly; since from the extremity of the descending arc down to *c* it acts contrary to gravity, and from *c'* up to the end of the ascending arc it acts with gravity, but as it always retards the pendulum of course it diminishes the arc. On the other hand, in the recoil escapement the action during the middle part of the oscillation is the same as in the dead escapement, but towards the extremities of the arc the force acts with gravity not only in the descent of the pendulum, but also

in its ascent during the recoil; and therefore any increase of the force will make the pendulum swing faster, though at the same time the arc is increased by the action through the middle of the oscillation as in the dead escapement, and is not affected by the action at the extremities of the arc. The difference between the time of oscillation of a pendulum attached to a dead escapement and unattached being very small, the second difference, between the times of the same pendulum with different degrees of force in the escapement, must be exceedingly small; which accounts for the accurate 'performance' of clocks with this escapement.

36. This kind of reasoning however will not enable us to determine the actual amount of the errors arising from any particular amount of change in the force, or in the arc. The calculations necessary for obtaining these results are too complicated to be introduced here, but the results themselves are sufficiently simple. Let D be the difference in twenty-four hours between the time of the day's oscillations of a free pendulum and the same number of oscillations of a similar pendulum attached to a clock with this escapement; a the angle of vibration on each side of zero; c the angle at which the impulse begins, c' the angle on the other side of zero at which it ends; W the clock weight, and h its fall in a day, M the weight of the pendulum, and l its length; then it may be proved that $D = \frac{Wh}{Ml} \frac{c'-c}{2\pi a^3}$ very nearly, provided that c' and c are not larger than about $\frac{a}{2}$. Suppose for example a to be 2°, and $c'-c = 20'$, $W = 2$ lbs. and $h = 9$ inches (which,

though less than usual, is sufficient for a highly finished clock with light wheels), $M = 14$ lbs. and $l = 39$ inches; then D will $= .8$ of a second.

But it must be remembered that the daily error in the going of the clock is not D, but the *variation* of D due to a given variation in the force which arrives at the escapement, and to the change in the arc of vibration, which will vary both from changes in the force and the friction on the dead part of the pallets. Now if the force of the clock is increased by a small amount $d\,W$, and the corresponding change in the arc is called da, then it follows, on the principles of the differential calculus, that the increase of D, or

$$d\mathrm{D} = \mathrm{D}\left(\frac{d\,\mathrm{W}}{\mathrm{W}} - \frac{3\,d\,a}{a}\right).$$

To this must be added the circular error, which we found to be (assuming it to be entirely uncorrected by the pendulum spring) $10800\,ada$. Therefore the whole daily loss of time will be

$$\frac{\mathrm{W}\,h}{\mathrm{M}\,l}\,\frac{c'-c}{2\,\pi\,a^3}\left(\frac{d\,\mathrm{W}}{\mathrm{W}} - \frac{3\,da}{a}\right) + 10800\,ada.$$

If we took the friction on the dead part of the pallets into account, we should introduce another small term showing a farther increase of time, and depending upon the pressure on the pallets and the *coefficient of friction*, or the ratio of the friction to the pressure (which is said to be from $\frac{1}{7}$ to $\frac{1}{10}$ between well polished and oiled surfaces of brass and steel), and also depending like the others on $c' - c$. Both for this reason, and because the dead friction diminishes the arc of vibration, the effect of which we shall see presently, it is by no means to be taken for granted that, because a constant friction on the pendulum through equal angles on each side of zero produces no *direct* effect upon the time of a vibration, therefore the friction in the dead escapement on the circular part of the pallets does no harm. We shall see a remarkable proof of the extent to which it diminishes the ability of the pendulum to resist the other disturbances, in an escapement (47) in which these other disturbances are much reduced, while the dead friction is much increased. Indeed it is obvious without either calculation or experiment, that the more friction there is, the larger must be the impulse required to make up for it, and consequently the larger will be all the errors connected with the impulse.

37. We see now the true cause of the accuracy of the dead escapement, and also how we are to set about it, to make this accuracy as great as possible. For though we cannot determine the proportion which the increase of the arc bears to that of the force, since it depends upon the varying friction of the different parts of the clock, yet we see that they have a *tendency* always to correct each other; and whenever the state of the clock is such (as in one experiment I actually found it to be) that the arc increases just one-third as much as the clock-weight is increased, those two parts of the error will exactly counteract each other: and the ratio of the increase might happen to be such as to compensate the circular error also. It generally happens, however, that as the clock gets dirty, the force and the arc decrease in such a proportion that the loss of time preponderates.

But there is one case in which the opposite effect not unfrequently takes place to the surprise of those who know the common result of a decrease of arc, and of which for some time I could not myself discover the reason. Church clocks will often be found in a few months after they are put up to increase their arc of vibration considerably, and at the same time to *gain*. This increase of arc arises chiefly from the decrease of friction on the dead part of the pallets, owing to the teeth and pallets polishing themselves more perfectly than had been done by the maker. Moreover in most clocks the quantity that we have called D is much larger than in the above example; and therefore the terms depending on D are much larger than the term containing the circular error. Consequently the term $D\frac{3\,da}{a}$ may preponderate over both the other terms; and as it has a — sign the clock will then gain while the arc increases.

It may be as well to explain that when a clock gains it is said to have a + *daily rate* of so many seconds, and when it loses, a — rate; and it should be remembered that these signs are the reverse of those which indicate the decrease or increase of the *time* of an oscillation. I may also remind the inexperienced reader that the goodness of a clock is indicated, not by its rate, but by the variation in its rate.

38. The effect which I have just now mentioned, of the self-polishing of the pallets is of course only temporary; and the general effect of a decrease of force and of arc in a dead escapement is, that the clock gains a little, whereas a common recoil escapement loses considerably as the arc decreases; and this has led to the adoption of a small recoil in the place of the dead part of the pallets, especially

in turret clocks, which are more liable to changes of friction than others. This recoil may be given by striking the circle of the dead part of the pallets, not from the axis of the pallets, but from a point a little below that axis, in the line of centres of the pallets and the scape-wheel, which produces a circle with a higher degree of curvature, and therefore raises the teeth a little after they have dropped on to the pallets: and the farther the pendulum swings the greater is the degree of recoil. This is commonly called the *half-dead* escapement.

39. There are some other things to be learned from the above expression for the daily error of a dead escapement, and some of them apply to all escapements. First, we observe that, as the weight and length of the pendulum are in the denominator of the fraction, the larger they are the less the errors of the clock will be; and this is the case with all escapements, and with all the errors, whether of friction or anything else, connected with the escapement; for it is quite a vulgar error to suppose (other things being equal) that a heavy or long pendulum requires a heavier clock weight than a short and light one, except that of course in large clocks the pendulum spring is stiffer, and the whole of the machinery heavier, and so requires a larger weight to move it than in small ones. The best turret clocks have 2, or 1½ seconds pendulums, which are about thirteen and eight feet long respectively, and the bob sometimes as much as four cwt. Now if the same clock had a one second pendulum with a bob of half a cwt., instead of a two seconds pendulum with a bob of four cwt., it would go just thirty-two times worse; or in other words,

if with the long and heavy pendulum it varied a minute in a month, with the other pendulum it would vary above half an hour.

40. The next independent quantity in the equation for D or dD is $c' - c$, or the difference between the angle at which the impulse begins and the angle (on the other side of zero) at which it ends, which is called the *angle of escape*. And we see that the smaller this difference can be made the smaller all the errors of the escapement will be, as indeed was apparent from the general reasoning independently of the exact value of D. The limit to the smallness of $c' - c$ is merely a practical one, depending upon the accuracy of the construction of the escapement, and upon the length of the pallets (by which I mean the arms that carry the pallets), for of course the longer they are the smaller will be the angle $c' - c$ corresponding to a given linear space required for the tooth to fall upon. The length of the pallets can only be varied in two ways; either by increasing the wheel and pallets together, or by increasing the number of teeth which the pallets embrace.

41. But it is to be observed that as you increase the length of the pallets you also increase the linear space over which all the friction acts, both the friction during the impulse and the dead friction; and if the wheel remains of the same size, the pressure, to which the intensity of the friction bears a certain proportion, will be the same; and so the total quantity of the friction will be increased by increasing the number of teeth embraced by the pallets in order to increase their length; for the radius of each pallet, drawn from the pallet arbor to the corner of the slope,

must be a tangent to the circumference of the teeth of the scape wheel, in order that the teeth on each side may act equally, and for the same arc of the pendulum, upon the slopes of both the pallets. The pallets therefore are seldom made to embrace more than the space of $10\frac{1}{2}$ teeth, or $11\frac{1}{2}$ at the most, when the wheel has thirty as usual.

42. Again it is not desirable to increase the size of the wheel beyond what is necessary for its proper strength in proportion to the number of teeth, because its *moment of inertia* increases even more rapidly than its size, and so causes it not to follow the pallets so quickly: and when the wheel is too large, the teeth may often be heard to jump or chatter on the pallets, from the length of the drop and the great linear velocity they have acquired when they are suddenly stopped. In astronomical clocks, or 'regulators' as they are called, the scape-wheel is generally two inches in diameter or a little more, and $c'-c$ can be made as little as $20'$ and ought never to be more than $30'$. In turret clocks five inches is quite enough for the diameter of a scape wheel with thirty teeth; and as that will allow more than twice as much linear space to the same angle as a wheel only two inches in diameter, $c'-c$, may be made as little as in a regulator. I have improved the going of a church clock, which was very well made in other respects, by opening the pallets wider, as they had been so set that the tooth fell on the circular part a good way above the slope, instead of as near to it as possible; and they fortunately admitted of adjustment.

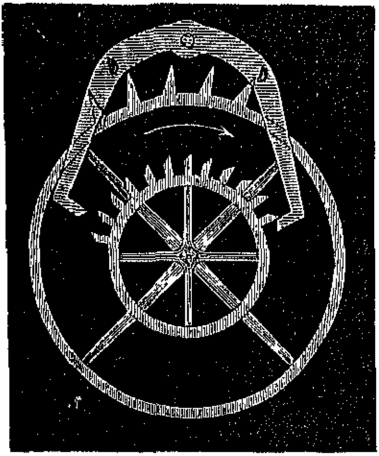
43. I have said nothing about the size of $c'+c$ as well as $c'-c$, because that quantity does not enter into the

value of D. But it is evident that the larger these angles are, the longer the impulse will last and the less dead friction there will be for the same degree of oscillation; and also the less suddenly the teeth have to drop, and consequently the more closely they will follow the pallets at the beginning of the impulse. But on the other hand the friction occurs during the impulse instead of occurring on the dead part; and the question between long and short impulses is one which is perhaps better determined by experiment than theory; the result however both of theory and experience seems to be in favour of a short impulse, especially as it requires a less arc upon the whole, and less maintaining force. Mr. Dent makes c', the larger of the two angles not much above half a degree, and the angle of oscillation $1\frac{1}{2}°$ in his astronomical clocks, and some of them are going with only a weight of four lbs., and the pulley, falling three feet in the eight days. A clock of this sort is also *safer* than one in which the angle of impulse is nearly equal to the whole arc of vibration, for in that case a little diminution of the arc from any accidental cause, such as freezing of the oil, will cause the clock to stop. This was what the old clockmakers meant when they said that the *excursion*, or the excess of the angle of vibration above the angle of escape, ought to be large.

44. There remains to be noticed one other ingredient in the equation for D, viz. $\frac{Wh}{a^3}$; for these quantities evidently depend on each other, as you cannot increase the arc in a given clock, but by increasing either W the clock-weight, or h its fall in the day. As was observed before, it is impossible to say practically what increase of arc da any given

increase of Wh will produce; but it is certain that the arc increases much more slowly than the weight; and, moreover, as the arc is increased, the quantity of dead friction is increased; and, therefore, on the whole, it is found that no good is done by adding to the weight in order to increase the arc. (This remark will not apply to the next class of escapements in which there is no dead friction.) But if you can increase the arc by diminishing the friction on the pallets, or improving the suspension of the pendulum, that is a clear gain; and accordingly the less weight and fall a clock requires to make the pendulum vibrate a given arc (other things being equal), the better the clock will go. For this purpose the pallets ought to be made as hard as possible; and in highly finished clocks they are made of jewels; sapphires I understand are the best. It seems to be a question whether steel or brass teeth work best upon jewels: upon steel pallets there seems to be no doubt that brass teeth work with less friction than steel and require less oil; but the brass should be hammered so as to make it as hard as possible.

45. Various contrivances have been proposed for diminishing the amount of dead friction, such as having separate pallets for the dead part of the action, which are to be left behind by the pendulum as it advances beyond the angle of escape (e'), and carries the impulse pallets with it. It will be seen, when we come to *remontoire* escapements, why this plan is objectionable, besides the difficulty of constructing it. Perhaps it might answer to put a large and a small scape-wheel on the same arbor, and short and long pallets on the same pallet arbor, the small wheel to give the



impulse on the long pallets, and the teeth of the large wheel to be stopped by the short pallets containing only the dead part, which however is to have a small recoil in it. In that case the impulse might be given through a small angle near the middle of the vibration; and the pressure which causes the dead friction would be less from a large wheel than a small one, and the space to be travelled over on the dead part of the short pallets would also be less than on long pallets; so that in every way there would be an advantage as regards friction. This may be called a *duplex* escapement, as it agrees with the escapement of that name in watches. It would require considerable accuracy in its construction, but not more than another, which I shall mention presently, as having been constructed, and at work.*

46. There is another form of the dead escapement, which does not differ in principle from the common one, but has some mechanical advantages over it, especially for large clocks. It is called the *pin-wheel escapement*. It will

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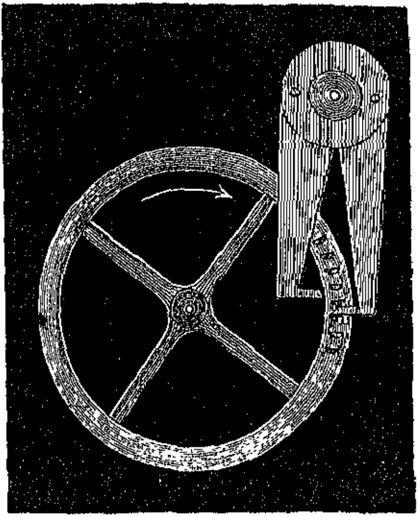
* I have made this and several other drawings in this book more with a view to an intelligible exhibition of the action of the parts, than to their actual or proposed construction.



be sufficiently clear from the drawing, that the pins are set on the face of the scape wheel instead of teeth on its edge, and that the two pallets, instead of embracing about one-third of the circumference of the wheel, are put so near together as to leave room for only one pin to pass between them; and the end of one slope should be just over the beginning of the other. The pins are only semi-cylinders, since the upper part of the cylinder could not act, and cutting it away allows the pallets to slip through close above the teeth, so as to waste as little drop as possible. The advantages of this escapement are, first, that it does not require so much accuracy of construction as the other; for in the common one if every tooth is not exactly in its right place, with reference to every other at the distance of ten or eleven from it, the escapement is liable to stick, and if the clock is going with a heavy pendulum a tooth is then pretty sure to be broken; whereas if every successive pin in the pin-wheel escapement is nearly at the same distance from the one immediately before it they are sure to clear the pallets: secondly, if by any accident a tooth of the common scape wheel is broken the wheel is ruined; whereas if a pin is broken a new one can be put in in a few minutes: thirdly, many more pins can be put into a wheel of given size, so as to clear the pallets, than teeth of the usual shape; and therefore there is less drop and waste of power at every beat, and the wheel turns through a less angle and with less velocity, and therefore with less friction on its pivots, and can also have a larger number of leaves to its pinion, the advantage of which will be seen when we come to consider the wheel work: fourthly, both strokes on the pallets being downwards, instead of one downwards and the other upwards, there is less shake in the pallet arbor; in a common escapement the difference of stroke on the up and the down pallet can generally be distinguished by the sound.

The only disadvantage of this escapement, as far as I know, is that the force of the cylindrical pins on the pallets is not so uniform from the beginning to the end of the impulse as with sharp teeth and pallets with straight slopes; in fact, the slopes ought strictly to be concave, in order to make the inclination of the tooth to the pallet the same at the end as at the beginning of the impulse. This however could not be done without the introduction of greater evils than the very small variation in the force. The pin escapement has been long used by the best makers of turret clocks both here and in France. It is not used in the Exchange clock, because it is not so well adapted for jewelled pallets, which that clock has. Mr. Vulliamy makes the pins of steel acting on broad pallets, portions of turned cylinders, and without any recoil; diminishing the radius of the cylinder, or setting the same pallets on longer arms, would give them a small recoil. Mr. Dent uses hard brass wire pins acting on pallets, not flat, but having the cross section a segment of a circle, and he makes the escapement 'half dead.' The scape-wheel for a 1½ sec. pendulum, with forty pins in it, in the two clocks I shall mention, is not quite four inches in diameter; this shows the small amount of drop which this escapement requires compared with the common one.

MR. AIRY'S DUPLEX SPRING ESCAPEMENT.

47. Before I proceed to the next class of escapements, and by way of introduction to them, I will describe the one I alluded to just now, which was invented by the astronomer royal, and of which three or four specimens have been made by Mr. Dent: one of them is now going in his shop in Cockspur-street. In order to prevent the inequalities of force of the train affecting the impulse on the pendulum, there are two scape-wheels and two pairs of pallets, one for the stop, and the other for the impulse: the stop-wheel is the one connected with the train, and the impulse-wheel rides on the same arbor, and is connected with the other by a spiral spring. The stop-wheel is let go by its pallets, which have no sloped faces, just before a tooth of the impulse-wheel would arrive at the slope of its pallets, and so the tooth is carried down the slope, and the impulse given by the force of the spring only. In fact, if the reader turns to the drawing of the duplex escapement in page 64, and supposes those two wheels reduced to the same size, and

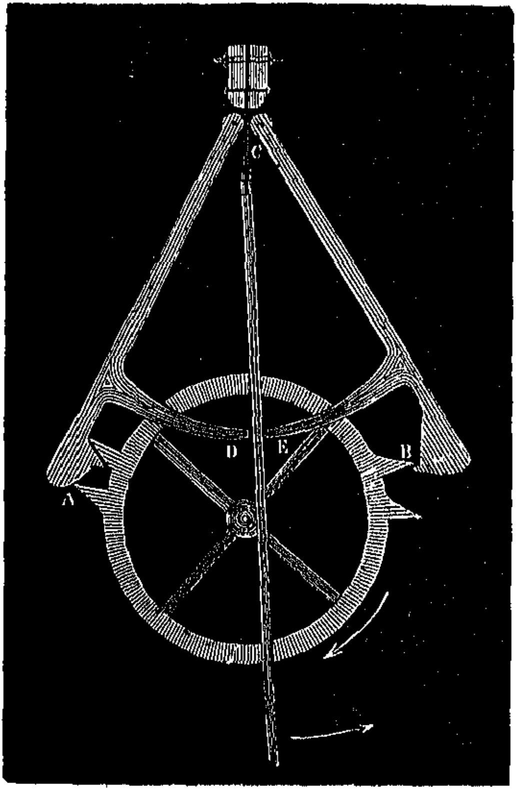
connected by a spiral spring instead of by screws, it will represent this escapement (which I may observe is not the one suggested by Mr. Airy some years ago in his paper in the 'Cambridge Philosophical Transactions'). The advantage of it is that the impulse is constant, or at least has no greater variation than that of the force of the spring arising from changes of temperature, which is much smaller than the variations in force caused by the friction of the train; with however this not immaterial exception, that the impulse-wheel turns with more friction, riding on the arbor of the other wheel, than if it turned on pivots as usual. Moreover the dead friction is that due to the train, and is very much greater than usual. The reader may form some some idea of the amount of force consumed by this friction and the additional weight of the second scapewheel, when I state that (reducing the falls to the same amount) the weight employed in driving this clock is more than twice as much as that employed in driving one of Mr. Dent's second-rate regulators, vibrating the same arc, and more than three times the weight of one of his first-rate regulators, also with the same arc; notwithstanding the numbers of the pinions of the clock with the duplex escapement are higher than those of either of the others, and the clock is made with the utmost care. And it is not surprising that this large amount of friction more than counterbalances the advantages of this escapement, and the clock does not go so well as a first rate regulator with the common dead escapement. Both these objections might probably be diminished; the first by making the stop wheel ride upon an arbor or stud set on the frame, and carrying the pivot of the impulse wheel in the manner I shall have to describe in a church clock lately made according to some suggestions of my own (177); and the second by using a large and light stop-wheel with short pallets in the manner above described (45).

REMONTOIRE ESCAPEMENTS.

48. Escapements of the kind just now described, (so far as the impulse wheel is concerned) in which the impulse is given to the pendulum by a small separate weight or spring, independently of the force of the train, are called by the French *remontoire* escapements, because the clock train winds or lifts up the maintaining force at every beat or at some given number of beats of the pendulum. They have long exercised the ingenuity of clockmakers; so long indeed and generally so unsuccessfully, that they appear to be considered by some people the philosopher's stone, or the perpetual motion, of clockmaking. It would be impossible to describe in any reasonable compass the various inventions that have been made for the purpose, both for clocks and chronometers. For chronometers they have always hitherto failed, and I have no doubt they always will; not only on account of the excesssive trouble and difficulty of constructing them on so small a scale, but because a chronometer train is so light that there is nothing like the same friction and waste, and therefore variation, of force between the main-spring and the scape wheel as there is in clocks, especially turret clocks, for which remontoires are most required. But that they can be made and ill answer for clocks, both large and small, is fully proved by

several examples of them which I shall describe as actually now at work with complete success, besides the one which I just now described and which may be considered an escapement of the 'transition style' between dead and remontoire escapements, or rather between an escapement remontoire and a train remontoire.

49. When the impulse is given to the pendulum by a small weight or weights, instead of a spring, raised at every



beat or other interval, they are called *gravity* remontoires, or merely *gravity escapements*.

The most simple, though not the earliest form of the gravity escapement is this. A C, B C, are two arms turning separately on pivots at C which coincide as nearly as possible with the axis of suspension of the pendulum. At the lower ends of the arms are two pallets of the shape in the drawing, so that a tooth of the scape wheel will slide along the sloped part and raise the arm until it comes to the little detent or hook at the end, which stops the tooth: the tooth at B is here represented as stopped, and the tooth at A ready to raise the arm A C, as soon as the other arm is pushed farther out so as to set the wheel free. The arms have projecting pieces, D, E, reaching down to the proper distance to be met by the pendulum rod. The pendulum is here drawn as going to the right and just touching the projecting piece E of the arm B C: as the pendulum goes on it will raise that arm and set the wheel free to raise the other arm; and the pendulum will carry the arm B C with it as far as it swings, and when it descends again the arm will descend with it, not only as far as the place where it was taken up, but farther, that is, until the slope of the pallet B rests upon the next tooth of the wheel, or upon some fixed stop set in the frame at the proper height. The maintaining force upon the pendulum depends therefore, first, upon the weight of the arms, and secondly, upon the difference between the angle of the pendulum when it takes up each arm in ascending and leaves it in returning. If the arms, instead of acting by their own weight, were so counterbalanced that their weight did not act upon the pendulum, and were fixed by short and rather stiff springs like a pendulum spring at C, the action would be evidently just the same, only it would then be a *spring*, instead of a *gravity* remontoire; and if not counterbalanced, it would be a compound of the two.

50. This simple form of the escapement will do as well as any other to explain the general advantages, and the mathematical conditions to be observed in the construction of all these escapements, whatever may be their mechanical peculiarities. The advantages of them are evidently these: first, the impulse depends upon the action of a given weight pressing on the pendulum through a given distance (that is a given difference between two distances) and communicated without any friction, except the inconsiderable friction of the pivots at C; the force is therefore independent of all variations in the friction in the train and escapement. Secondly, there is nothing corresponding to the dead friction of the dead escapement, or the still greater friction of the recoil escapement; and therefore the pendulum will be much less liable to variations in its arc of vibration: indeed there is no friction at all except the momentary friction of unlocking the teeth when the pendulum first catches the arms; and therefore the pendulum will swing a given arc with less maintaining force. A third advantage has been supposed to be that the pendulum may be left quite free for some distance during the middle of its arc, since it need not be made to take up one arm as soon as it leaves the other: this however we shall find to be the worst construction, though it has been the most common.

51. Now if we could be sure that the pendulum would never vary *at all* in its arc, this escapement would be mathematically perfect. But there is no such thing in practical mechanics as perfectly invariable motion; and it unfortunately happens that if the arc of vibration varies at all, from change in the density of the air or the little friction which exists, it produces much worse effects with this escapement than a much larger variation of the arc produces with the dead escapement. For as was shown in the recoil escapement, the additional force, or weight of the arms, acts with gravity both in the ascent and descent of the pendulum, and therefore the farther it ascends with this additional force acting upon it, the more the time of its oscillation will be diminished. In order to show the amount of this acceleration, let D as before be the increase of the time of all the oscillations of a seconds pendulum in a day when attached to this escapement: c the angle (from zero) at which the pendulum takes up each arm, c' the angle at which it leaves the other arm; only you must remember that c' is now supposed to be on the same side of zero as c, and not on the opposite side as in the dead escapement; W, h, M, l, and a, indicate the same things as in the dead escapement. Then it may be proved that

$$D = \frac{-Wh}{Ml\pi a^2 (c-c')} \left(\sqrt{a^2-c^2} + \sqrt{a^2-c'^2}\right)$$

The — sign indicates that D is here a decrease of time instead of an increase. c and c' may be any angles we please, except that c' must be less than c, or there will be no impulse given to the pendulum, and also c cannot safely be more than a—30′, since the unlocking of the wheel has to take place while the pendulum is moving through $a - c$. It will be found that whatever value of $c - c'$ we take, subject to these conditions, the value of D in this escapement is many times greater than in the dead escapement. And since D is so much larger in the remontoire than in the dead escapement, it was perhaps natural to suppose that the variations of D (which are the error of the clock) must be larger also; and experience was supposed to confirm this theory, for however carefully the remontoire escapements have been made, they have not generally equalled the accuracy of the dead escapement, and when they have, only by their mechanical advantages and very perfect construction.

52. But although this conclusion would be perfectly correct if applied to any construction of the remontoire escapement which a clockmaker would spontaneously adopt (which accounts for experience appearing to confirm theory), there is nevertheless a construction, which, though not very convenient, is quite practicable, and will render the variations of D so small as to be inappreciable for any probable variation of the arc of vibration. In order to produce this effect, it may be proved that c, c', and a must be made to satisfy this condition:

$$\sqrt{a^2 - c^2}\ \sqrt{a^2 - c'^2} = \frac{a^2}{2}$$

Many different values of c and c' for any given value of a will theoretically satisfy the equation; but practically the number is very limited by the circumstances mentioned a little while ago. For suppose that we intend a to be 120′ and c' to be on the same side as c; then in order that $a - c$

may $= 30'$, c must not be more than $90'$, and we shall find that the corresponding value of c' is very nearly $78'$. But this construction is barely practicable, for the angle through which the impulse has to be given, and through which the arms have to be raised by the escapement will be only $12'$, and these small angles are extremely difficult to manage with accuracy in the construction of the escapement. Probably the only way in which it can be done is by such a construction as that which many persons must have seen in the window of Mr. Dent's shop, made, however, without any reference to this theory, in which the action takes place near the bottom of the pendulum, and so the linear space corresponding to a small angle is sufficiently large. This construction, however, is on another account very inferior to that in which c and c' are on opposite sides, or the arms act upon the pendulum through a considerable angle on each side of zero; as may be seen at once from the fact that, in that case, $c-c'$, which occurs in the denominator of the value of D and its variations, becomes $c+c'$, and therefore the value of D and dD is very much smaller than when c and c' are on the same side of zero, or the pendulum is free in the middle of its swing.

53. Suppose then that c and c' are on opposite sides, and $a=120'$ as before; then one construction that will answer is to make c and c' each $=\frac{a}{\sqrt{2}}$ or $84'\cdot 86$, so that one arm is always taken up just as the other is left. And as it is not safe to allow the pendulum to touch one arm before the other has reached its lowest point, and is ready to catch the scape-wheel, any value of c' larger than c is practically inadmissible; and on the whole the best form of the remon-

toire escapement evidently is that in which e and e' are on opposite sides of zero, and each $= \frac{a}{\sqrt{2}}$ or $\cdot 707a$. In that case the equation in § 51 assumes the more simple form,

$$D = -\frac{Wh}{Ml\pi a^2}\sqrt{\frac{a}{c} - 1},$$

and the variation of D for da a given small variation of a,

$$\text{or } dD = \frac{Wh}{Ml\pi a^2}\,\frac{1 - \frac{2c^2}{a^2}}{\sqrt{\frac{a^2}{c^2} - 1}}\,\frac{da}{a}$$

Now in order to see what the error of such a clock will amount to for certain small variations of the arc, we may put for $W\,h$ half its value in the dead escapement, as that is sufficient for a well-made clock of this sort, there being no dead friction to overcome; and as $a = 120'$ and therefore $c = 84'\cdot 86$, or $\cdot 0246$, $\frac{Wh}{Ml\pi c^2} = 8\cdot 7$; and we shall find that if a increases or decreases from $120'$ to the following amounts, the clock will *in either case* gain, but no more than the following small quantities daily:

a =	$123'$	dD =	$\frac{1}{100}$	of a second
——	$122'$	——	$\frac{1}{220}$	——
——	$120'$	——	0	——
——	$118'$	——	$\frac{1}{200}$	——
——	$117'$	——	$\frac{1}{80}$	——

Therefore as the arc will never spontaneously increase, it should be so adjusted when the pivots and pallets are cleaned, that a may exceed the normal value by a little more than $1'$, which it will do if the pendulum is made to swing to $120'$ in a clock in which c is $84'$; and then the arc may diminish as much as $4'$ or $5'$ without producing any sensible effect upon the rate of the clock; and such a clock may be pronounced theoretically perfect.

If c should be made a more convenient size, say 1° for $a = 2°$, the clock will lose for an increase and gain for a decrease of arc; but it will only lose $\frac{1}{8}$ of a second a day for a decrease of 5′, which is a very large variation of the arc for such a clock; and, therefore, even with this construction, it would probably go better than any dead escapement. These escapements have however, I believe, been always made on the plan of leaving the pendulum free in the middle of the swing, which, as we have seen, is the worst construction, especially as the angles were sure to be made very far wrong, from the difficulty of making them right on that construction.

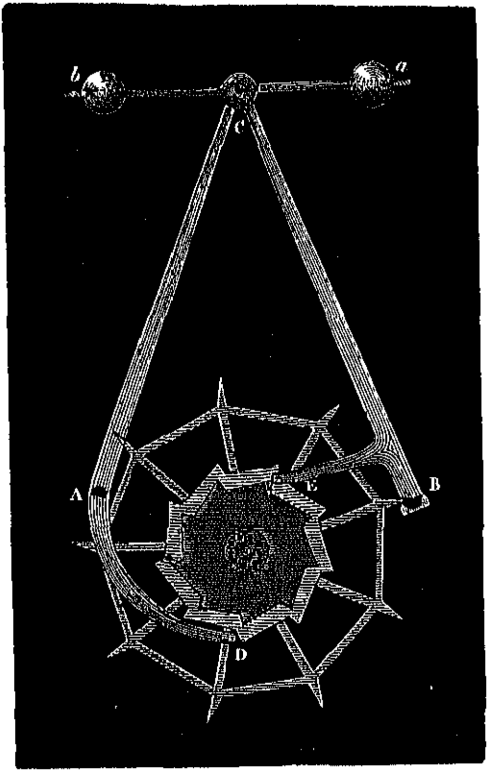
54. There is however a certain mechanical difficulty in the construction of these escapements, which has probably been a greater obstacle to their use than the supposed mathematical objection. It will be easily perceived on looking back to the drawing of the escapement that there is some risk of the teeth of the scape wheel, when driving up the slope of the pallet, sending the arm too far by causing it to rise too quickly; and if it does, the hook at the end of the slope will not catch the tooth as it ought to do, and two or three teeth will slip past at once: this is called *tripping*. Various contrivances have been resorted to to prevent it; the most obvious is to put the slope on one arm, and the hook on another by the side of it; the arm with the hook is not allowed to fall so low as to require raising by the wheel, and so is always ready to receive a tooth when it is not raised by the pendulum; the pendulum

raises both the hook-arm and the pallet-arm together. This is Cumming's escapement, with the omission of some balls which he added by way of giving 'momentum' to the arms, in complete ignorance of mathematical principles, that being the very thing we ought to avoid as much as possible; and with the arms set upon springs instead of turning on pivots and carrying weights, it is Hardy's escapement, which the transit clock at the Cambridge Observatory has. But this is a complicated arrangement; and I believe even these stationary hooks (as they may be called in contrast to the others) sometimes trip from the blow of the tooth against them, unless they are *undercut*, or the teeth so made to fit the hooks that they cannot be disengaged by the pendulum without causing a slight recoil in the wheel and a resistance to the pendulum, which is of course very objectionable, especially as the force required for it will vary in different states of the clock. It will now be seen why the similar contrivance which I mentioned (45) as having been applied to the dead escapement does not answer; for the separate arms carrying the dead part of the pallets are liable to these same objections, and moreover on account of their own weight they affect the pendulum after the manner of a remontoire escapement without the angles properly adjusted.

MR. BLOXAM'S ESCAPEMENT.

55. A form of the gravity escapement has lately been invented by Mr. Bloxam, the inventor of the dipleidoscope (9), which when it is so made as to satisfy the proper conditions respecting the angles, (which he had unfortunately

not discovered until after he had constructed the escapement without any particular regard to the angles), seems likely to possess every qualification that is requisite to produce a perfect escapement, and with no inordinate difficulty of construction. By Mr. Bloxam's permission



I give a drawing, and a short description of it, as it will require to be made. A C, B C are the two arms, carrying flat stops corresponding to the common hooks at A, B, one of which is represented as stopping a tooth of the scape wheel at B. I have omitted the pendulum in the drawing for greater distinctness. The scape wheel has only nine teeth, and consequently moves through 20° at each beat, and its motion therefore will take a longer time, or will be more gradual, than if it only moved through 6° as usual. Concentric with the scape wheel and fixed to it are two other wheels of the form called *cam* wheels in machinery, though no great accuracy is required in the form of the teeth for this purpose. These wheels are so placed that one of the nine teeth or cams of the smaller wheel is ready to raise the arm B C by means of the projecting piece E when that arm is left by the pendulum at its lowest position; and while the wheel turns through 20° the small wheel is to raise the arm B C through 84′, if the pendulum swings 2°; and in like manner the larger cam-wheel raises the other arm through the same angle, by means of the projecting piece A D.

The reason why two cam-wheels are required, in order to completely satisfy the condition respecting the angles, is, that as one arm must be raised by the lower part of the wheel and the other by the upper, they cannot both be carried through the same angle, unless the wheel which has to work the longer arm is larger than the other.

Now the effect of this arrangement is, first, that the arms are raised with much less friction than when a tooth slides along a sloping pallet; secondly, the rise taking a longer time, there is no risk of the arms being driven too far by their own momentum; thirdly, the pressure of the teeth of the scape-wheel upon the stops is much less than in a wheel of the usual number of teeth, and consequently the friction at unlocking is much less; in fact the pressure is so little that the stops, instead of being undercut, may be sloped a little the other way without the pressure being sufficient to lift them, and therefore the friction at unlocking may be reduced to nothing. To show how safe from tripping this escapement is, I have seen the weight in Mr. Bloxam's clock pulled by hand, and so increased to more than double of what was required to work the escapement, without its exhibiting the least tendency to trip. And it may be observed, that even if the angles should not be quite correctly adjusted, the causes of error are so much reduced by the absence of nearly all friction, that hardly any variation of the arc can take place: in fact Mr. Bloxam tells me that he has never been able to detect a variation in the rate of more than a second a week even in his clock as now made with the angles of escape not half the proper size. I have no doubt it might easily be made on a large scale with perfect accuracy and no great amount of trouble, and it might also be combined with a remontoire in the train, for the purpose of effecting those objects for which a train remontoire, letting off about every half-minute, is desirable in turret clocks, independently of their accuracy of performance, for which see § 172, &c. It may be convenient to state the proportionate dimensions which I find will be required for the different parts. Suppose we intend the radius of the scape-wheel, (which is very light, being cut out of a plate of thin steel) to be 2·5 inches, then we must make the other parts as follows:—

Radius of larger cam-wheel	1·24	supposing the angle $a = 120$ and $c = 84'$
Radius of smaller cam-wheel	1·	
Distance from centre of wheel to axis of arms - - -	7·45	
Length of arms (to pallets)	7·	

These dimensions will allow $\frac{1}{20}$ inch for the depth of locking if it occupies an angle of 24′, and $\frac{1}{16}$ if it occupies as much as 30′: anything between the two will do very well. If the scape-wheel is half this size everything else must be half the size. The counterpoises *a*, *b*, are added because I believe the arms cannot be made light enough to do without, when they act through an angle of 168′.

56. Other escapements without number have been invented: indeed there is a story of a celebrated clock-maker saying he would undertake for a wager to invent a new one every day. But a description of them would be of no use in a merely practical treatise, as the escapements themselves have never come into use. Perhaps the most ingenious, as well as curious, was Harrison's, who, when he was only a carpenter, invented it to save himself the trouble of having to go so frequently to oil the escapement of a turret clock, which he had undertaken the care of. It has no friction on the pallets, but has an immense recoil; and though a degree of accuracy is attributed to one made by him, which is evidently fabulous, it is said (which is probably not fabulous) that nobody else could ever make them to answer. A description of it may be seen in several of the Encyclopædias, and in Reid's 'Treatise on Clock-making.' We will proceed to consider another matter, which though apparently minute is of great importance.

COMPENSATION OF PENDULUM.

57. All the substances of which a pendulum rod can be made increase in length as their temperature increases. Let l be the length of the rod, $d\,l$ its increase for any given number of degrees of heat, and $d\,t$ the corresponding increase of t, the time of the vibration of the pendulum, then (remembering that $d\,l$ is very small compared with l, and so $\left(\frac{d\,l}{l}\right)^2$ may be neglected),

$$\frac{t+dt}{t} = \frac{\sqrt{l+dl}}{\sqrt{l}} = 1 + \frac{d\,l}{2\,l}; \text{ or } dt = \frac{t\,dl}{2\,l} = \frac{t\,m}{2}$$

if for shortness we put m for $\frac{dl}{l}$ the rate of expansion of the material of the rod for some given number of degrees of heat. And the daily loss of the clock, which we may call $d\,T$, will be 43,200 m in seconds, whatever is the length of the pendulum.* The following is a table of the value of m, or the rate of expansion in length of the following materials, for 10° of heat:—

White deal - - - -	·000023
Flint glass - - -	·....48
Steel rod - - - - -	·....64
Cast iron - - -	·....66
Iron rod - - - - -	·....7
Brass - - - - -	·...10
Lead - - - - - -	·...16
Zinc - - - - -	·...17
Mercury (in bulk, not length)	·..100

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* This same calculation will show us how much a pendulum ought to be shortened when it loses, or lengthened when it gains—assuming the weight of the rod to be immaterial compared with the bob. Suppose for instance, that 32 threads of the screw are contained in an inch, and that the whole length l of the rod is 45 inches; then each

Thus for a common pendulum rod of iron wire, we see that dT for an increase of temperature of only $10° = 43200 \times {\cdot}00007 = 3$ sec.: or the clock will lose a minute in three weeks; and if the pendulum is adjusted to go right in winter, it will lose about a minute a week in summer. Even a deal pendulum would vary nearly a third as much as this.*

58. We want therefore some contrivance which will *compensate* this expansion of the rod; that is, which will always raise the *centre of oscillation* of the pendulum as much as the expansion of the rod lets it down. If the rod had no weight, and the bob were merely a heavy point, this would be the same thing as saying that the *centre of gravity* of the bob must be kept at the same height; and as the bob of compensated pendulums always is heavy in proportion to the rod, this is approximately true, and with the addition of a small quantity, according to a simple rule, it is sufficiently correct for practice.

59. The most simple kind of compensated pendulum is one in which the material of the bob expands so much more

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thread, or each complete turn of the nut, will raise the bob by a quantity $= \frac{l}{1440}$, which we may, as above, call m; and the corresponding daily alteration in the time being $= 43{,}200\ m$, will be just 30 seconds. Consequently, if the head of the screw is divided, as it usually is in regulators, into 60 divisions, with a pointer over them, a turn of the screw one division to the right or left will accelerate or retard the clock half a second a day.

* You must not expect to find this result actually take place in a common house clock: the other causes of disturbance in such clocks are so large, that they may either overbalance or aggravate the effects of heat upon the pendulum rod. I believe they will generally be of the former kind, since the heat makes the oil more fluid, which in the common recoil escapement will accelerate the clock.

than that of the rod, that a bob of moderate length resting on the bottom of the rod will raise its own centre of gravity as much as the expansion of the rod lets it down. A deal rod, with a leaden bob about $\frac{2}{7}$ths of its length, will be thus compensated. For the ratio of the expansion of the wood to that of the lead is we see about $\frac{1}{7}$; and consequently a bob whose centre is $\frac{1}{7}$th of the length of the rod from its bottom, will compensate the rod.

60. But we want to know how much longer than the length of the simple pendulum the rod must be in order to carry a long enough bob. Let l, as before, be the simple pendulum, or (as we assume it to be) the distance from the point of suspension to the centre of gravity of the bob; x the additional length required, or half the length of the bob; m the rate of expansion of the rod, n that of the bob. Then $(l+x)\,m$, the expansion of the rod downwards, must $= x\,n$, the expansion of half the bob upwards; or $x = \frac{l\,m}{n-m}$. This calculation will make the leaden bob of a 39 inch deal pendulum about 13 inches long, and the rod 45½. It is found, however, on account of the difference between the centre of gravity and the centre of oscillation, that the proper length is 14⅓ inches; and the practical rule may be given, to add $\frac{1}{10}$th to the length of compensating material determined by calculation on the hypothesis of the centres of gravity and oscillation being identical.

61. The principle of the mercurial pendulum is exactly the same as that of the wood and lead. The rod is of steel, and the mercury is put in a cast-iron cylinder (in the best pendulums) screwed to the bottom of the rod. Only it is to be remembered that the rise of the mercury in the

cylinder will be diminished by the lateral expansion of the cylinder itself, and consequently a rather greater height of mercury is required than that given by merely taking the tabular rate of its expansion. The old form of mercurial pendulum was that of a glass cylinder standing on a *stirrup* at the bottom of the rod. The chief advantage of the iron cylinder is that it can be made of a more regular shape, and that it takes the same temperature as the rod, and communicates it to the mercury more rapidly than the glass. Captain Kater, in his chapter on compensated pendulums in 'Lardner's Mechanics' (from which the above table is taken), says he has successfully employed, as a cheap mercurial pendulum, one made entirely of glass, the rod and cylinder being blown in one piece. The height of mercury required in an iron cylinder is stated to be 6·6 inches. The best mercurial pendulums are actually tried and adjusted for compensation at various temperatures, by adding or taking away mercury as may be required.

62. But mercurial pendulums are too expensive for common use, and would cost nearly as much as the clock itself, for pendulums weighing several cwt.; and wood is open to the objection that it is liable to twist, and can never be completely protected from damp, which of course alters its weight; and therefore some other kind of metallic compensation is necessary. Now it will be seen on looking at the table, that the ratio of the expansion of steel to that of brass is ·61. Consequently, if we can make a pendulum of steel and brass rods in the proportion of 1 inch of steel to ·61 of brass, and so arranged that the brass rods carry the bob up while the steel ones let it down, it will be com-

pensated. The only convenient way of doing this, is to make the brass rods (for there must evidently be a pair of them, one on each side of the main rod) rest on a nut at the bottom of the main steel rod, and hang another pair of steel rods from the top of the brass ones to carry the bob at their lower end. Therefore the one length of brass has to compensate two lengths of steel; and since the compensating rods must not reach above the point of suspension of the pendulum, it will be evident that this cannot be done with only one pair of compensating rods; and in fact it can only just be done with two pairs; for suppose the brass rods to be quite as long as the main steel rods, or all the rods to be of the length l, we must have $2\,l\,n$ the expansion of the brass rods upwards $= 3\,l\,m$ the expansion of the steel rods downwards; and since $\frac{m}{n} = \cdot 61$, this is only just possible; and if iron is used instead of steel, it is *not* possible, since the ratio of the expansion of iron and brass is ·7, which is more than $\frac{2}{3}$. And therefore a completely compensated *gridiron* pendulum of steel and brass requires nine bars (as the compensating rods must go in two pairs), and one of iron and brass could not be made with less than thirteen bars. Gridiron pendulums have now been superseded by those which I shall next describe.

68. The greater expansion of zinc than brass obviates the necessity for so many bars, the ratio of iron and zinc expansion being only ·41; and a very good and elegant and tolerably cheap compensated pendulum can be made of iron and zinc rods; or, what is the more simple and common form of it, a zinc tube may be made to rest on the regulating nut at the bottom of the main rod, and this zinc tube carries an iron tube fastened to it at the top, and carrying the bob at the bottom. In compensation by rods it is necessary to add more than $\frac{1}{10}$ to the length of zinc and brass given by the calculation in § 60, because the difference between the centre of gravity of the bob and the centre of oscillation of the pendulum is greater where there are compensating rods or tubes of considerable weight, than where the compensation is contained in the bob: in other words, the bob has to be lower to produce a pendulum equivalent to the required simple pendulum when the rod is heavy than when it is light. I find that for a 1½sec. pendulum (88 inches), for which the zinc compensation, if the centres of gravity and oscillation were identical, would be 61·6 inches, it is necessary to add nearly $\frac{1}{6}$ to complete the compensation, taking into account the weight of the rod and tubes, the bob being a cast iron cylinder a foot long; and the total length of the pendulum, from the top of the spring to the bottom of the bob, requires to be nearly 97 inches instead of 88.

64. There is another kind of compensation, a compound of both the former kinds, which was invented by Smeaton, and was generally used by Holmes, a celebrated clockmaker of the last century. The rod is of glass, and it carries on a collar at the bottom a zinc tube about 12½ inches long, from which is hung an iron tube, which carries a lead cylindrical bob of the same length as the tubes themselves, and enclosing them, so that the pendulum looks as if it had merely a glass and lead compensation. I wonder it is not more frequently made now that glass is cheap, as it requires no polishing as a zinc and steel pendulum does,

or is thought to do, and I suppose it is equally effective. It is evident that the expansion of the zinc and *half* the length of the lead upwards has to compensate that of the glass and iron downwards.

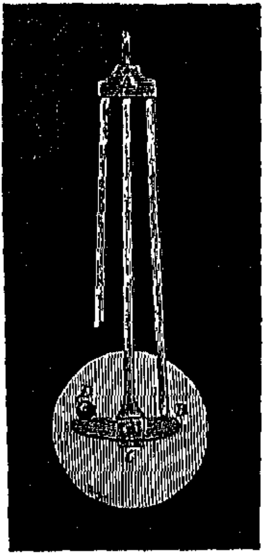
65. In all cases a little additional compensation is required on account of the variation in the strength of the pendulum spring, which diminishes as its temperature increases. The amount of it depends upon the stiffness of the spring with reference to the weight of the bob and the length of the pendulum, and can only be ascertained by trial. According to some experiments published by Mr. Dent, the compensation of the spring requires about $\frac{1}{8}$th to be added to the ordinary compensation of the steel rod in a seconds pendulum of the usual weight; and consequently about half must be added to the compensation required for a wooden rod. I am told that in a short pendulum the compensation required for the spring was a great deal more than $\frac{1}{8}$ of that required for the steel rod; and indeed it is evident that this must be the case, for the elasticity of the spring must produce less effect upon the rate of a long pendulum than a short one of the same weight; and therefore in a 14 or even an 8 feet pendulum the compensation required for the spring must be very little indeed compared with that of the rod.

66. It is evidently a considerable advantage of a mercurial compensation that it affords the means of actually trying the pendulum and adjusting it so as to compensate accurately both the variation of the strength of the spring and the expansion of the rod at any two extremes of heat, by merely diminishing or increasing the quantity of mercury; which cannot be done without a good deal of trouble

in a pendulum made of solid metals. With the view of obtaining a cheaper mercurial compensation than that of a cylinder full of that metal I have suggested the following method, which as far as I know is new. Make a hollow cast iron ball with a short neck in which a piston fits very accurately. It is evident that if the ball is nearly filled with mercury and the piston can be made to fit mercury-tight, the expansion of the mercury will raise the piston through a height which depends upon the ratio of the thickness of the piston to the quantity of mercury which the ball will contain. Consequently if the ball is fixed to the bottom of the pendulum rod by a thing like a pump sucker, and the piston is made to carry the bob resting on a short cross bar, this apparatus may be used to compensate the pendulum, and will require only a small quantity of mercury. And as the depth of the piston in the ball does not signify, the quantity of mercury can be varied at pleasure; or it may be altered by putting bits of iron into the ball in the place of so much mercury. The only difficulty is to make the piston mercury-tight. Mr. Dent has succeeded in doing this for a 39 inch pendulum, even with such a heavy bob as 70 lbs. I doubt however whether it would be safe to use this plan where the mercury is constantly under such a heavy pressure as that; but perhaps it may answer for pendulums of twice the weight of those which are usually put to astronomical clocks at present, and of which the mercury alone costs £4 or £5.

67. There are two other kinds of compensated pendulums which have this peculiarity, that they do not depend upon the difference of the rates of expansion of their ma-

terials. The first of them, the lever compensation, was it seems tried by Graham, the inventor of the dead escapement, but abandoned by him for the very superior mercurial compensation; and was afterwards completed by Ellicott. I have lately seen it used in some small French clocks, and therefore it may be worth describing.

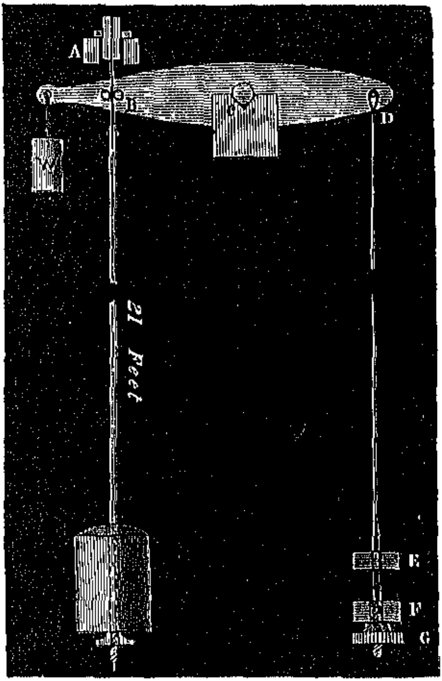


A C is the main rod of iron, B D a lever resting on a fulcrum at C fixed to the bottom of the rod. (There is another lever, exactly the same, only set the opposite way, which is with a portion of the rod on the left hand omitted in the drawing for greater clearness). A is a strong collar fixed to the main rod anywhere near the top. Between this collar and the short end of each lever is put a bar, either of brass or iron, and the bob is supported by pins or rollers D resting on the long ends of the two levers. Now if the ratio of the long arm to the short arm of each lever is the same as that of the amount of expansion of the rod A B to that of the main rod, it is evident that the bob will be kept in the same place. Theoretically A may be anywhere, and A B may be either of iron or of brass; but the less expansion A B has the shorter must be the short arm of the lever, which is objectionable for several obvious reasons. A more serious objection to the pendulum altogether is that, on account of the friction at D, which is sliding friction of a bad kind, the bob was found to move by jumps, and moreover the compensating rods must be very thick to avoid bending. It has indeed been proposed to remedy this by supporting the greater part of the weight of the bob on a spring, and leaving only just enough weight on the levers to keep them to their bearing; but it is complicated enough already, and can have no advantage over the more simple zinc compensation, until the laws of nature are altered, and all metals expand equally.

68. The other kind of homogeneous compensation is, I think, but for one practical difficulty, much more promising; for if this difficulty can be got over, it would afford the means of compensating a pendulum 50 feet long and a ton in weight, with as little trouble and expense as a small one, as well as a very convenient method of making the finer adjustments for time, without stopping the pendulum. If the pendulum spring, instead of bending from a fixed point, is passed through a slit in a fixed cock, and is itself carried by another cock above, which admits of being raised as much as the pendulum increases in length, the effective length of the pendulum will evidently remain the same. Therefore if the upper cock is made to slide in a vertical grove and rests upon an upright bar of the same material and length as the pendulum, standing on a firm support at the bottom, the expansion of this bar upwards will exactly compensate the expansion of the pendulum rod downwards. And in favour of this method it is said that if the bar and the pendulum rod are taken from the same piece, we are sure that their rate of expansion will be the

same, whereas no two experiments with different pieces of the same metal give exactly the same result. But as this rod acts by pushing, not by pulling, it would have to be very thick to support the cock for a long and a heavy pendulum without bending.

69. The same object might however be effected in another way and with several incidental advantages, provided the objection I shall mention can be removed. Let the pendulum be hung from a fixed cock A as usual, only a few inches higher, and with the spring reaching a few inches above the end of the pallet arbor. B C D is a cast iron lever with its pivots at C turning in two Vs in a strong cock firmly fixed to the wall. At one end D is fixed a wire or rod D E F of the same length and material as the pendulum rod. A squared portion of this rod passes through the cock E to keep it from twisting, and ends in a screw passing through another cock F, and has a nut G below.



E and F would be cast all in one piece and fixed to the wall. The other end B of the lever at the same distance as D is from C is so made as to clip the pendulum spring, but not so tightly that it cannot slide under a moderate pressure; and in order to produce this pressure and keep the lever steady, a weight W is hung on to that end of the lever. Then as the pendulum rod lengthens, the compensating rod lengthens too, and lets the weight W pull down the end B of the lever, and so makes the effective length of the pendulum the same as before. As the motion would not have to be quite $\frac{1}{20}$ of an inch to compensate a 14 feet pendulum for 40° of heat, it is not of the least consequence that the end of the lever moves in a circular arc and not in a straight line; and the longer the pendulum is the longer the lever should be in order to diminish the curvature of the arc which its end has to describe.

The practical objection to this kind of compensation, to which I referred, is, that any alteration in the length of the spring is found to affect the rate of the pendulum, not uniformly, but in some variable way which is not reducible to any fixed law. This is entirely an experimental question, and I have no means of knowing to what extent this variation takes place, or whether any experiment exactly similar to this has been tried. I do not suppose that this compensation would be equal to the others; but considering the advantages of long and heavy compensated pendulums over short or uncompensated ones, and the impossibility of compensating very long pendulums at a moderate expense by any of the usual methods, I should be inclined to try it where the building affords facilities for a pendulum as long as 21 feet (2½ sec.), such as there is in Doncaster Church, with however a very inferior clock, quite unfit for the work it has to do. I may add that when the tower shakes under the ringing of the bells, as all towers that have not spires on them do with a heavy peal of bells, a long and heavy pendulum is especially necessary.*

70. There are a few other matters relating to pendulums which may as well be mentioned here. First as to their shape. Until lately pendulum bobs, except mercurial ones, were almost universally of the shape of a common magnifying glass or lens, and such pendulums are therefore called *lenticular*. This shape was adopted on account of its passing through the air with less resistance than any other figure that could conveniently be used. But they are liable to this objection: if one of these bobs were set on a rod with its broad side instead of its edge towards the direction of motion, the pendulum would vibrate in a different time (independently of the resistance of the air), because the moment of inertia of a circular plate turning round an axis placed anywhere at right angles to its plane is greater than if the same axis were placed in the plane. Consequently if the pendulum rod should from any cause get so placed or twisted that the lenticular bob (which approaches to a flat plate) does not always vibrate with its largest or central circle in the plane of motion of the pendulum rod, the time

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* I take this opportunity of correcting a mistake in Southey's well-known book called *The Doctor*, wherein he laments over the removal of the old peal of bells in Doncaster Church on account of the inability of the tower to bear them any longer. The old peal *was* removed in 1835, but only to be recast, the two largest bells being cracked; and the new peal was put up in the same year, and is one of the heaviest peals of eight in the kingdom, the tenor weighing 32 cwt.

of vibration will vary; and in nearly every common clock the bob of the pendulum may be observed to have that kind of twisting motion which is familiarly termed *wobbling*, especially when it swings a large arc.

But this twist of the bob can produce no effect upon the time of vibration, if the bob is a cylinder or any other solid of revolution having the rod of the pendulum for its axis. And the pendulum is also less likely to acquire that motion, if the bob is such a solid of revolution, than if it presents a surface unequally exposed to the resistance of the air, as the lenticular bob does if it is ever so little twisted. A sphere (which Holmes put by Smeaton's advice to the Greenwich Hospital clock) is inconvenient, not only because of its requiring so much width for the pendulum to swing in, but because a slight error in making the hole for the rod, which throws it out of the axis of the sphere, causes a greater disproportion between the mass on each side of the rod than in a longish cylinder or a prolate spheriod having the rod for its axis. Therefore upon the whole a cylinder is probably the best shape for the bob; and there is no objection to its top being made a portion of a sphere, when the bob is made of cast iron, as it rather improves the appearance, and also prevents anything from settling upon the top, as sometimes happens in church clocks, with bits of mortar and the like, the effect of which we shall see presently. The pendulum of the clock in the frontispiece is of this shape. It may be convenient to state that a cast iron cylinder 9 inches wide and 12 inches high, with a spherical top rising 2 inches more, and a hole 2 inches wide all through it for the compensation tubes, weighs 2 cwt.

within a very few pounds; and the centre of gravity of the bob is about $7\frac{1}{4}$ inches from the top.

71. The next point is the regulation of the pendulum. The common and well-known method is to raise the bob by a screw at the bottom of the rod when the clock loses, and to lower it when it gains; and the quantity by which this must be done for any given loss or gain of the clock may be determined approximately in the manner stated in the note at page 83. But it is difficult to do this without stopping, or least disturbing the pendulum, which requires the clock to be set again; and therefore two other methods are used for making the finer adjustments in regulators and in turret clocks with heavy pendulums, which require a strong and coarse thread to the screw, and must be held steady while the screw is turned to avoid twisting the pendulum spring. One is, to have a small weight sliding on the rod and kept in its place by a spring collar, which allows it to be moved up and down by a blow with a small hammer; raising it accelerates the pendulum, only in a much smaller degree than raising the heavy bob, and therefore it admits of greater accuracy. The other method is to have a few small weights to lay on the top of the bob; adding them of course raises the centre of gravity, and of oscillation, and accelerates the pendulum; if they were put at the bottom of the bob they would produce the contrary effect. When the bob has a round top the little weights may be set on spikes (of which there should be a pair, one on each side of the rod), or in a cup, or on a ring on the top of the bob.

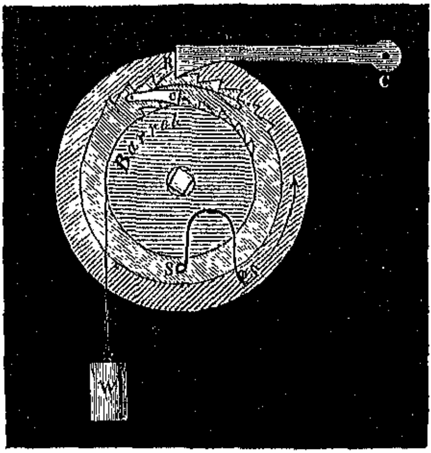
The amount of acceleration produced by any given small weight put on the top of the bob, will evidently vary with the length of the bob *directly* (that is with the height above the centre of gravity or oscillation at which the little weight is placed), and the length of the rod, and the weight of the bob, *inversely*. Let l as before be the length from the top of the pendulum to the $c.g.$ of the bob (assuming it as before to be identical with the centre of oscillation), b the distance of the $c.g.$ of the bob from its top, M the weight of the bob, m the little weight to be added, and $d\,l$ the quantity that the $c.g.$ is raised thereby; then it is easily proved that $dl = \frac{m\,b}{\mathrm{M}+m} = \frac{b}{r+1}$ if we put r for $\frac{\mathrm{M}}{m}$. And as in § 57, the corresponding daily acceleration $d\,\mathrm{T}$ will $= \frac{43200\,b}{(r+1)\,l}$ in seconds. Suppose, for example, that $\frac{b}{l} = \frac{1}{12}$ (as if l is 88 inches, a $1\frac{1}{2}$ second pendulum, and $b = 7\frac{1}{4}$ in.), $\mathrm{M} = 2$ cwt., and $m = 1$ lb.; then $d\,\mathrm{T} = \frac{43200}{12 \times 225} = 16$ sec.; or an ounce weight put on the bob of such a pendulum would accelerate it just one second a day. The pendulum of the Exchange clock, a 2 seconds pendulum with a bob 20 inches long and weighing above 3 cwt., was regulated some time ago by putting a penny on it.

We may now leave the pendulum and escapement, which may be considered the mathematical parts of a clock, and return to the consideration of the merely mechanical parts.

HARRISON'S GOING BARREL.

72. The general construction of the going or time-keeping part has been explained already (18). But for clocks that are to keep accurate time, there is yet something wanting, viz., a contrivance to keep them going while they

are being wound up, for that of course takes the action of the weight off the clock, and so the scape-wheel will not escape unless some equivalent pressure is applied to the train. In common house-clocks and the cheapest watches there is no such contrivance, and they stand still while they are winding up; but in all others the apparatus which is applied for the purpose is that invented by Harrison, and called the *going barrel*, or *ratchett*, in weight clocks, and the *going fusee* in watches and spring clocks. This drawing shows the arrangement of it. The barrel with its ratchett and click are the same as before explained; but the click *c* is not now placed on the great wheel, but upon another wheel riding on the arbor of the barrel between the great wheel and the barrel ratchett: this wheel has also ratchett teeth cut upon it, but turned the opposite way to the barrel ratchett, as shown at R, and the click R C belonging to it is a long arm turning on a pivot C in the clock-frame; and this second ratchett wheel is connected with the great wheel in any convenient way by a spring S S, having one end fixed on the ratchett wheel, and the other end pressing against a pin on the great wheel. The action is this: while the



clock is going, the weight pulls the barrel and both ratchetts to the left, and the going ratchett, by means of the spring S S, presses the great wheel in the same direction; and as the clock goes on, one tooth after another of the ratchett R slips under the long click, and this causes the drop which may be heard about every five minutes in regulators and in good watches. When the weight is taken off the barrel by winding up, the going ratchett immediately flies back a little towards the right, but is stopped as soon as one of the teeth arrives at the click, and there it is held; the spring continues to press the great wheel as before, with nearly as much force as when the weight is acting, and so keeps the wheel in motion for the short time that the clock is winding up.

DIAL WORK.

73. The only thing that remains to be described in the going part of clocks is the dial work, or the machinery by which the hands are moved. The minute hand is set upon the square end of a socket or pipe, which fits rather tightly on the long projecting arbor of the centre wheel. It must not be quite tight, or the hand could not be put forward or backward when the clock wants altering; and the requisite degree of tightness or friction is obtained as follows. The pipe on which the hand is set is about an inch long, and has a wheel fixed to its other end (the use of which will be described in the next section, and which may be called the hour-wheel), and the pipe slides on to the arbor pretty easily; but before it is put on, a slightly bent oval spring, nearly as long as the diameter of the wheel, with a square

hole in the middle, is slipped on to the arbor with the concave side outwards, and the square hole fitting on to a corresponding square, cut for about $\frac{1}{10}$th of an inch on the arbor, so that the spring is always carried round with the arbor; then the pipe is put on, and the wheel rests against the concave side of the spring; then (omitting the hour-hand for the present) the hand is put on, and generally a small cap or collar in front of it; the collar is pushed back so as to force the wheel more tightly against the spring, and a pin is put through the end of the arbor just in front of the collar. It is evident, therefore, that the hand and its pipe will be kept steady on the arbor by the pressure between the collar and the spring, and the friction of the spring upon the hour wheel, but that it can be turned when necessary. Sometimes the hole in the spring is left round instead of square because it is less trouble, but it is a slovenly practice, and it requires much more pressure to produce the same degree of steadiness when the friction of the spring acts upon the small diameter of the arbor than when it acts upon the large diameter of the hour wheel.

74. Besides carrying its own hand, the long hand pipe, and the wheel belonging to it, have to turn the short hand, and also in striking clocks to let off the striking part. The form of hour-hand which was formerly used in regulators is this: the minute-hand socket has a pinion on it, and this pinion works a large wheel with twelve times as many teeth as the pinion, which therefore turns round once in twelve hours; this wheel has the twelve hours engraved upon it, and there is a hole in the dial though which the figures appear, and a stationary hand or index pointing to the proper figure.

This might have been done in a still more simple way, and without incurring the friction of that wheel and pinion, by setting the hour circle on the arbor of the great wheel, which turns in twelve hours. It is of no consequence that it would be turned with the arbor in winding up, because you would only have to stop winding at a place which would leave the proper figure of the hour circle under the index.

These moveable hour circles are now abandoned, on account of the small figures moving past a hole being so much less easy to see than a hand moving in the usual way. The now obsolete day-of-the-month wheels, which required setting for five months in the year, showed themselves through a hole in the same way. But if a hand were merely put in the place of the moveable dial, it would turn the wrong way, that is the opposite way to the other hand; and therefore an intermediate wheel is now put between the pinion of the minute-hand socket and the hour-hand wheel, and the multiplier 12 (when there is no striking) may be divided between these three wheels and their pinions as we please; and in regulators the hour-hand usually points to a separate dial, or set of figures engraved on the lower part of the large dial, and corresponding to the small dial for the seconds-hand on the upper part.

There is another way, which is sometimes adopted, of working the short hand on a separate dial, and without the intervention of this second wheel, viz., by putting the hand upon an axis which goes through the frame of the clock, and carries a wheel working into another equal wheel fixed on to the great wheel, which turns in twelve hours. The great wheel itself is so large that it would be inconvenient to have another of the same size working into it, and this is the reason of this other wheel being fixed to it. There is so much less friction in this way of working the hour hand directly from the great wheel than by going up to the centre wheel and then down again by two more wheels, that I wonder it is not more commonly adopted. The only objection to it is that if the hands want setting they must be set separately; but a regulator clock requires so little alteration that the hour hand never has to be meddled with unless the clock has been allowed to stop.

75. All these methods however are different from that which must be used when both the hands turn on an axis in the middle of the dial, as they do in all clocks except astronomical ones, and sometimes in them. In that case there is a wheel of the same size as the wheel we have called the hour wheel placed by the side of it and driven by it, and therefore turning the *wrong* way once in an hour, and having on its arbor a pinion with six or more leaves: this wheel may be called the *reversed hour wheel.* Its pinion drives a wheel with twelve times as many teeth, which is fixed to a socket or pipe riding on the former one; and this pipe carries the hour hand, and will evidently turn in the *right* direction once in twelve hours. This hour hand pipe is not indeed really carried by the minute hand one; for in order to take the weight of it off the centre wheel arbor, it rides upon another fixed socket or pipe surrounding the minute hand pipe and set upon a cock which extends over the minute hand wheel and is screwed to the frame: this fixed cock and pipe are called a *cannon.* So that the apparent central axis of the hands of a common

clock consists, first, of the centre wheel arbor; secondly, of the pipe to which the long hand is fixed; thirdly, of the cannon; and fourthly, of the hour hand pipe; and, fifthly, if there is an alarum to the clock, of the pipe to which the little alarum dial is fixed. This arrangement of the dial work is the most clumsy part of English and French clocks. It is done better in the American; and I shall propose what I think a still better arrangement of it, in § 87, in connexion with another alteration of the usual construction of eight-day clocks. Occasionally the seconds hand is also set upon a thin arbor within all the others and travels round the large dial, instead of having a small one to itself: this is a very bad practice on account of the increased friction which it causes, and such clocks are rarely made now.

EQUATION CLOCKS.

76. The things called *Equation Clocks* belong to the subject of dial work; for they are (or rather were) clocks for showing, but not going, *true* instead of *mean* solar time; which was done by communicating a secondary or superimposed motion to the hands, so as to advance or retard them according to the equation of time for every day in the year. They were never in common use in England, though they have occasionally been made as curiosities; but Mr. Vulliamy says in his pamphlet before quoted, that until December, 1826, 'all the French public clocks of any repute were made to show solar time.' The machinery by which it was done was, as may be supposed, complicated; and as it is perfectly useless, and worse than

useless, and a description of it may be found in Reid's Treatise on Clockmaking and other books, I shall not describe it. For house clocks there appears to have been a somewhat more simple method of doing it, by making the dial itself revolve slowly, according to the equation of time, while the hands went uniformly in the usual way. The dial would have to turn about half round between November and February, the figure XII appearing nearly at the usual place of IX in November, and at III in February, with other smaller oscillations in the remaining nine months. And after all the ingenuity thrown away upon these contrivances, true time could not be shown by any of them as accurately as by a common clock, with an equation table such as that printed at page 11. For the equational motion was, in all the plans, communicated to the dial or dial work by means of a plate of an irregular oval form set upon a wheel revolving in a year; the form of the plate was such that the radii, from the axis on which it turned to the edge of the plate, were proportionate to the quantity by which the clock ought to be before or behind the sun; and the plate as it revolved pushed some moving frame work farther from the centre or nearer according to the time of year. And it is evident that no great accuracy could be obtained in this way except upon an inconveniently large scale.

MONTH AND YEAR CLOCKS.

77. Occasionally clocks are made to go for a month or even a year. This is done merely by the addition of one wheel or two below the usual great wheel, and increasing the weight to four or forty-six times as much as usual.

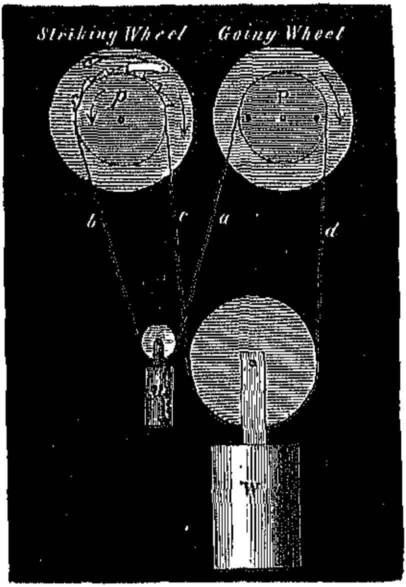
Occasionally two barrels are used, to avoid the great strain upon the teeth of one great wheel and the adjacent pinion. One string is then sometimes made to run off both barrels together, carrying one weight between the two lines; which however has a pulley for the string to pass through to keep its tension equal, though the pulley has no sensible motion. The barrels will of course turn half as many times round in the month or year as if one end of each string was fixed to the frame in the usual way, and the one weight was divided into two. Chronometers are also made to go long periods in a similar way, by the use of two or more main-springs to drive one wheel, as this secures greater uniformity of force than one very strong spring.

THIRTY-HOUR CLOCKS.

78. These clocks are seldom made now as English or French house clocks. Most of the Dutch and many of the American clocks however are so. When a thirty-hour clock winds up with a key like other clocks, in order that it may have only three wheels in the train, the minute hand arbor does not belong to a wheel in the train, but to a supernumerary wheel, which is driven by the great wheel in the same way as in one of the methods I described for working the hour hand of an astronomical clock, and the great wheel turns in two or three hours. In the Dutch clocks and the old English thirty-hour clocks, the arbor of the great wheel is not used to wind up by, but comes through the frame and carries a wheel which works the hour and minute hand wheels both together, being smaller than one and larger than the other: or some equivalent

arrangement, of which many varieties may be conceived. For as the arbor of the great wheel is used to carry this dial working wheel, it evidently cannot be used also to wind up the barrel; and accordingly instead of a barrel there is used a sort of deep pulley with spikes in it to prevent the rope or chain from slipping: this pulley is not fixed to the arbor but rides upon it, and it is connected with the great wheel by a ratchett and click as before described. One end of the rope carries the clock weight and the other end a little weight merely to keep the rope steady and to take hold of to pull up the great weight by when you wind up the clock.

79. There is however another way of applying this sort of spiked pulley, which deserves notice on account of its producing the curious effect of keeping the weight acting upon the clock, at the same time that it is being wound up. It is called the *endless chain* of Huygens. P is the spiked pulley fixed on to the great wheel arbor, not now by a ratchett and click but rigidly; *p* another spiked pulley which may ride either



on the same axis or on any other conveniently placed, and having a ratchett and a click fixed to the clock frame. The endless chain *a b c d* passes over both pulleys, and in the loop formed by *c d* on the right side of both pulleys it carries the weight W hung by a common pulley; a little counterbalancing weight *w* is hung to the other loop *a b*; this little weight is sometimes merely a large ring hung on to the chain. Now if the string *b* is pulled down by hand it will pull up *c* and so raise the weight W, which being hung by a moveable pulley will nevertheless still press upon the string *d* and so keep the clock in motion by pressing on the right side of the principal pulley P. If the clock has a striking part, *p* may be the pulley of the great wheel of that part, the click being fixed to that wheel; and then the clock may be wound up at any time when it is not striking. Only in that case it must be remembered that the weight will descend in half the time that it descends in when the pulley *p* never has any motion to the right, or the click is fixed to the frame; and the same will be the case with only a going part, if the click is fixed to the great wheel instead of to the clock frame, for then both pulleys will turn together; but while the clock is being wound up only half the weight will then act upon the great wheel.

SPRING CLOCKS.

80. There is yet another kind of clock, which differs from all that I have yet described in having for its maintaining power not a weight but a long spiral spring, which is coiled up in a box or barrel as tightly as possible when it is wound up, but with room to uncoil itself for a few

turns of the barrel, in doing which it moves the train which is connected with the barrel just as a weight does. The simplest construction, which is used in all the French clocks and watches, is this: the great wheel is fixed to the barrel that contains the spring; the outer end of the spring being fastened to the barrel, and the inner end to a strong arbor which goes through the barrel, turning in the caps of the barrel, and ends in the winding square, and also carries a ratchett wheel, of which the click is fixed to the clock frame, to hold it as you wind up. And therefore this kind of clock requires no maintaining power to keep it going while winding up; for the tension of the spring is acting upon the barrel at that time as much as any other, in fact rather more. But on the other hand the force of the spring is much greater when it has been just wound up, than when it is nearly run down; with however this remarkable, and apparently anomalous exception; that it is found that there is a certain position of the spring in which its force is nearly the same for three or four turns, but no more. Consequently, as a watch only requires a few turns to wind it up for a day, the variation in force in French watches is slight, compared with that in the clocks which go a week or a fortnight, and in which the spring has many more turns to make than in a watch. This is one reason of the inferiority of French watches, and still more so of clocks, to English ones, both in price and quality.

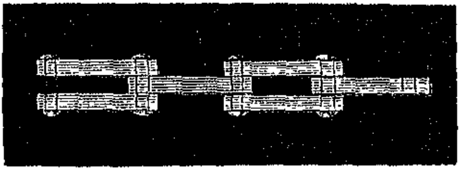
81. For this inequality of force is removed in English spring clocks and watches by the use of what is called the *fusee*. The fusee is nearly a cone, that is to say, a cone whose slant side is concave instead of straight, with a spiral

groove cut round it from one end to the other, as on the barrel of a weight-clock, for a string or chain to run in. The spring is enclosed in a barrel as before, but the barrel does not carry a wheel, and its arbor, instead of being used to wind up by, has a ratchett and click merely for the purpose of adjusting the tension of the spring. A catgut cord, or a chain, is wound round the barrel, and the loose end of it fastened to the thick end of the fusee. The fusee is fixed upon the winding arbor, and has the great wheel riding upon it with a ratchett, just as the great wheel of a weight-clock rides on the barrel arbor; and the best clocks and watches have a 'going ratchett' also. As the fusee is wound up, it draws the cord off the barrel along the groove until it is all wound off the spring barrel on to the fusee. And it is evident that when the tension of the spring is greatest, it is pulling at the thin end of the fusee, and when the tension is least it pulls at the thick end; and therefore, if the radius of the fusee is made to decrease, as the force of the spring at the corresponding point of winding up increases, the force communicated to the great wheel will be constant.

82. In order to prevent the cord from being broken by over-winding, there is a kind of lever fixed to the frame, with a hook to it, so placed that as the cord advances towards the thin end of the fusee, it pushes this lever aside, so that its hook catches hold of a long tooth projecting from the end or cap of the fusee, and stops it from being wound up any farther. As the cord recedes again, the lever is allowed to recede under the pressure of a small spring behind it, and by the time the fusee has made one revolution, the

lever and its hook have got out of the way of the long tooth.

83. Probably few readers of this book require to be told what the chain of a watch or a spring clock is like, but it is proper to describe it in a 'rudimentary treatise.' It consists, then, not of links set across each other, but of plates, alternately one and two, rivetted together; but the hole in the single plates is so large that the rivet does not stick tightly in it. Here are two pairs of links, drawn on a scale which the reader will think more fit for a drawing of the chains of a suspension bridge than of a watch or even a clock. A chain of this kind never twists, but will only bend in a plane (or nearly so) parallel to the plates of which it is composed.



84. These clocks are most frequently made to stand on a bracket, and always of such a size that their pendulums can only be about 10 or 18 inches long; and as their bobs are small also, we know what the result must be as regards their accuracy. However, when they are well made, with a fusee, and not exposed to a temperature which freezes the oil (which is much above the freezing point of water), they will go nearly as well as a coarsely made long clock of the old fashioned kind. Sometimes they require a good deal of trouble to set them so as to beat equally, for if they are not so set, they are very likely to stop, as they have generally, and the foreign ones always, very little force to spare. This position is not, as is commonly supposed, that of actual ver-

ticality, but merely of verticality relatively to the escapement; they ought indeed to coincide, but they frequently do not; and consequently after the bracket has been made quite level, it is found either that the crutch wants bending, or the clock raising on one side by bits of card. They are much more likely to stand steady, and also easier to adjust, if the two hind feet are taken off, and one put instead in the middle between where they were.

85. These are now almost the only English clocks (except regulators) that find any sale; and even these are getting fast superseded by the better class of American clocks, and by French ornamental clocks, neither of which, however, will last nearly so long. With the latter it is no doubt quite hopeless for us to compete, as, besides the greater cheapness of their labour, the French appear to possess what I may call a smaller eye and finger than English workmen, and they are able to perform delicate and ornamental work with much greater quickness and facility. And as those who chiefly regard the beauty of the figure of their clocks seldom care much about their entrails, they consider it of no consequence that a good English clock is better for the natural object of a clock than a foreign one. Whether it would be possible to *manufacture* clocks on a large scale as cheap as the American ones, I am not able to judge. I have been told that, but for the cases, it would. But unless the English clockmakers take some steps towards either altering the kind of clocks that they make, or can find out some cheaper mode of making them, there is no doubt that there will soon be no house clocks, except regulators, made in this country. The old-fashioned, full-length house clock is

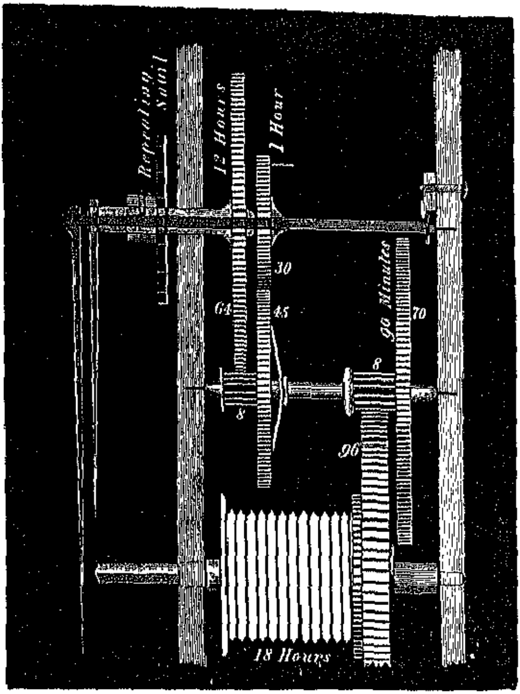
now nearly exploded, on account of its ugliness, size, and dearness, as compared with the American clocks, which go sufficiently well for ordinary purchasers.

No one who has seen the inside of an American clock can help seeing that ours are unnecessarily heavy, and waste a great deal of the force in merely overcoming their own inertia and friction. An American clock goes a week with both the weight and the fall for it not half of what they are in the common English clocks; and as a large pendulum requires no more force to keep it going than a small one, it is evident that about $\frac{3}{4}$ths of the moving power in our clocks is wasted. (The commendation of the American clocks cannot be extended to the fixing of their pendulums, which is as bad as possible.) I have also seen some very neat French clocks, about the same size as the American, but much more highly finished, and with dead escapements, going a week with a very small weight.

86. A clock might be made very much better than any English spring clock, or any of the foreign ones, and quite as cheaply as the old long clock, and at least equal to it in performance and very superior in appearance, and therefore more likely to sell, by making the case only of the length required for a seconds pendulum. This may be done in three ways: 1. By hanging the weights by three strings instead of two: the lower pulley should be let into the weight instead of occupying the height of 3 or 4 inches above it, and should be as broad as the space between the weights will allow. I have converted an old long clock into one of 'three-quarter length' in this way, and cut off the large and ugly and useless pedestal of the case. The

second method is to make the barrel ⅔ds of the usual diameter; and the third and best is to make the number of teeth in the great wheel half as many again. Or the second and third methods may be combined in any convenient proportion. In all these cases of course the weight will have to be half as large again, except that, as I said before, it is now unnecessarily heavy, because the wheels are so. I may observe also that the third of the above methods will require a barrel of only ⅔ds of the usual length, and therefore all the arbors and the space between the plates may be so much less. Mr. Dent now makes nearly all his regulators in this way, and such clocks take up no more room, except in length, than a common spring clock; and for all the reasons I have mentioned I beg to suggest the adoption of this size of clock to both the makers and the purchasers of clocks; the faces should be about the same size as those of common spring clocks; one door serves for the body and face, or the whole of the front and sides take off at once.

87. And with this alteration I think there may very well be combined that alteration of the dial work which I referred to in § 75, as it will also help the arrangement of making the barrel to turn only 11 times instead of 16 in 8 days. Those who are acquainted with the American clocks will see that this plan is partly borrowed from them. The arrangement will be pretty clear from this drawing. The scape wheel and second wheel will be worked by the centre or 90 minute wheel as usual, which may have 70 teeth driving a pinion of 7 on the second wheel with 54 teeth driving the scape wheel pinion of 6. I adopt these small numbers on the supposition that all these driven

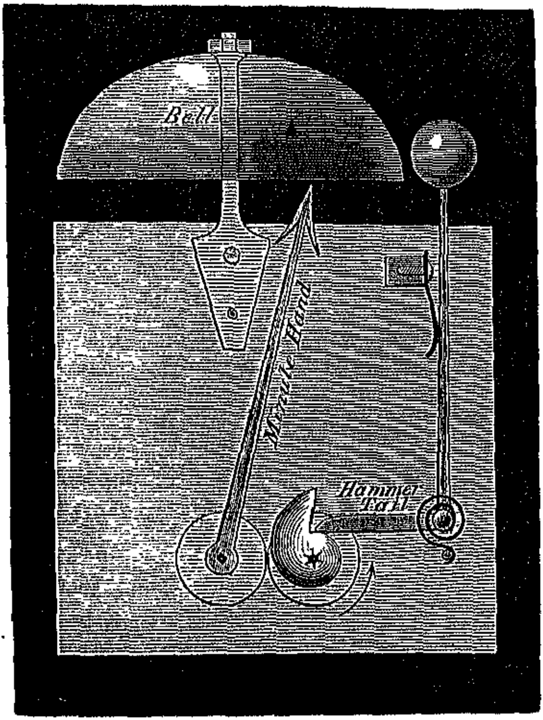


pinions are to be *lantern* pinions, as they are in the American clocks, which is one of the reasons of their going with such small weights, as will be explained in § 126 'on the teeth of wheels.' The pinion of 8 on the left side of drawing, not being driven, but driving the 12 hour wheel of 64 teeth, is not to be a lantern pinion but a common one, only hollow, as it is fixed to the wheel of 45 which rides on the centre wheel arbor and turns with it in an hour and an half, and admits of being moved on the arbor when you alter the hands, being held by the pin and the bent spring shown in the drawing, as before described in § 73.

The advantages of this plan are, first that the friction of the large and heavy 12 hour wheel pipe riding on the 'cannon' is got rid of, or rather that pipe is reduced in size so that it need not be any larger than the usual hour wheel pipe; secondly, the minute hand pipe is got rid of entirely, and consequently the weight and friction of that arbor is also reduced; thirdly, the 12 hour wheel is driven directly by the train instead of in the usual roundabout way; fourthly, the discharging pin is put on the hour wheel itself instead of on the usual reversed hour wheel, and consequently it must always agree with the hand; whereas at present clocks are not unfrequently put together so as to strike when the hand is nearly a minute from the proper place: the hour hand can also be adjusted by simply pulling its pipe forward when the minute hand is off, as there is room to slide the 12 hour wheel out of gear with the pinion that drives it. The hour arbor is to be kept in its place by a small collar at its end, over which there stands a cock which may be screwed on from the outside of the clock frame. The lifting piece of the striking part will have to be inside the frame; but that, as any clockmaker will see, is of no consequence, as it will only require a pin to go through the hole in the front plate to lift the click of the repeating work, instead of going through from the front to the inside to stop the pin wheel as usual. In the striking part the reduction of the turns of the barrel from 16 to 11 may be made (besides the methods above described for the going part) by increasing the pins and teeth of the striking wheel in the proportion of 8 to 10 and giving the great wheel 98 teeth instead of 78. And I have no doubt that if a spiral spring is put to the hammer, as I shall describe presently, and the higher wheels made as light as the American clock wheels, the present size of clock weight would still be quite sufficient in the striking as well as the going part. However I shall leave this to the consideration of clockmakers and proceed to describe the

STRIKING PART OF CLOCKS.

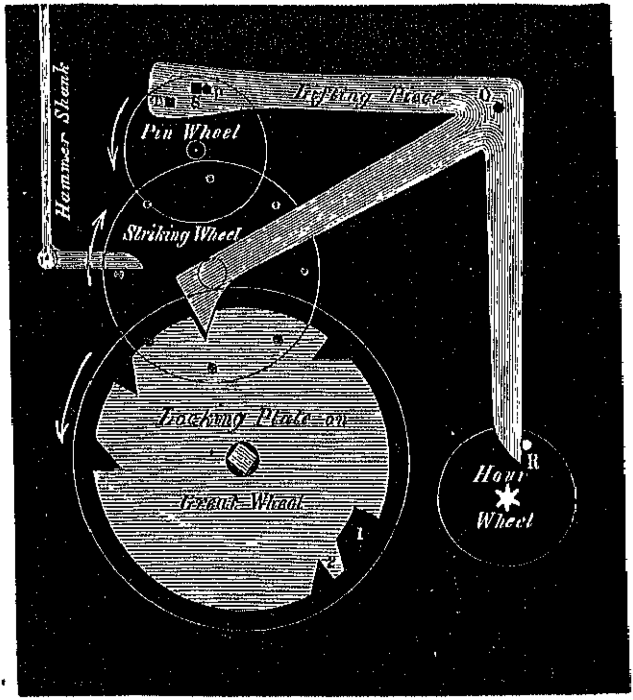
88. A clock may be made to strike *one* at every hour without any separate striking part, by merely putting a pin



into either of the wheels of the dial work that turns in an hour, and a *hammer tail* or lever over it, so that the pin will begin to raise the hammer about a quarter before the hour, and just slip from under it when the minute hand points to the hour. Instead of the pin there may be put upon the front of the wheel what is called a *snail*, which is a flat piece of metal cut into a spiral form, as shown in the drawing; the effect of which is that the work of raising the lever is distributed over the whole hour instead of having all to be done in a quarter of an hour, but with considerable friction. I have drawn the hammer as worked by a spiral spring, instead of the usual long and stiff spring, which produces a great pressure on the pivot, and is no better than the inside bit of a broken watch spring in any respect, and not so cheap to make and fix. The arbor should be made thicker than usual at the place where the spring is put on. This apparatus will require an addition of about one-sixth to the clock weight, as there are 12 blows to be struck in the 12 hours instead of 78, and the striking and going weight are usually about equal. Clocks of this kind are put in some of the Courts of Law at Westminster, and are just as good for a room as those that strike the number of the hours, since they call attention to the fact of the hour being up, and any body who does not know what the hour must be has only to look. They can of course be made cheaper than full striking clocks, which require a separate train of wheels, and which are made as follows.

On one of these wheels are placed any convenient number of pins so as to raise the hammer tail in succession In eight-day clocks the pins are put upon the wheel next to the great wheel, and are 8 or in coarse clocks 6; and the pinion having as many leaves as pins, the great wheel will turn in the 12 hours if it has 78 teeth, or one for every blow struck in 12 hours. In thirty-hour clocks the pins are set upon the great wheel. Above the wheel which has the striking pins there are usually two others, the highest of which drives a fan or fly to regulate the velocity of the train: a pendulum and escapement have been proposed for the same purpose, but the fly is perfectly sufficient. One of these two wheels has another office to perform besides driving the fly. The one above the striking wheel must turn exactly round for one or more blows of the hammer. I shall assume it to be once for every blow as it usually is.

89. The principle of all the various ways of letting off the striking part will be seen from the next drawing. A pin P in one of the higher wheels of the train, called the pin wheel, rests against a stop S on a lever, called the *lifting piece,* when the clock is not striking. This lifting piece turns on a pivot O and has a tail, which is raised by a pin R or a snail on one of the hour wheels of the going part when the clock is within a few minutes of striking, and this lets the pin P slip past the stop S on the lifting piece; but it is not allowed to go far, being presently detained by another stop T either on the same lifting piece or on another connected with it; the noise made by this is called giving *warning.* When the time is come for striking, the pin R slips from under the lifting piece and lets it drop, and so the pin wheel can turn round until the pin P has come to S again. But before that happens provision is made for getting S out of the way if the clock has to strike more than one.



This is done as follows: there is a large wheel called th
locking-plate or *count-wheel*, which turns in 12 hours, an
may therefore conveniently be put upon the great whee
The rim of this locking-plate is marked out into 78 div
sions, and then deep notches are cut in it at the successiv
distances of 1, 2, 3, &c., of the divisions, up to 12, a few o
which are shown in the drawing. The lifting piece has ano
ther arm which reaches as far as the locking-plate and has
tooth which just fits into the notches. Now while the fir
blow of any hour is striking and the pin wheel is makin

one turn, the locking-plate is turning also in the direction shown in the drawing; and in so doing the notch lifts the tooth of the lifting piece out and makes it rest on the rim until another notch has arrived for it to fall into; and the depth of the notches is such that the lifting piece is moved far enough to lift both the stops S and T quite out of the way of the pin P by the time it has gone once round, and they remain there until the clock has struck the proper number and the tooth of the lifting piece drops into the next notch in the locking-plate: which is in fact an hour dial if the notches are marked with the hours, as the number under the lifting-piece is always the last number the clock has struck.

Between twelve and two o'clock it will be seen on looking at a locking-plate there is one long cut instead of two nicks, as I have shown in the drawing, because the clock will strike one blow without having the lifting-piece lifted at all, except as the going part lifts it. And in like manner in the French spring clocks which are often made to strike one at the half hour, the count-wheel or locking-plate is divided into 90 parts instead of 78, and all the nicks are made as long as the one o'clock nick in clocks that do not strike the half hour.

Sometimes instead of a nick for every hour there is a pin with a slant side, which when the clock has struck the proper number raises the lever to catch the pin P in one of the higher wheels; when warning is given the lever is raised by the going part a little higher to let the pin P clear the first stop S and stop at the second T, and when it is completely let off the lever drops and the count-wheel moves on and lets it fall low enough to clear both pins. This of course is exactly the same in principle. The objection to the count-wheel method of striking is that if the clock is either caused to strike when it ought not; or the striking part is allowed to run down, or the clock put back past an hour, it will strike wrong the next time, and cannot be set right again without striking it round till it comes right; and even this is not what every body knows how to do; and it may be useful to those who have foreign clocks to be told that if you put your finger behind the clock or into the left side of it and lift up the only moveable thing you can feel, you can hardly fail to make it strike. There are several other modes of applying the locking-plate construction, which are occasionally used in turret clocks, but these are much the most common.

REPEATING STRIKING MOVEMENT.

90. The plan which has long been in use in all English house clocks allows the striking of any hour to be repeated as often as you please, or the clock to be stopped or put back past the hour,* or made silent, or to be run down, and still it will strike right as soon as it is made to strike again. Instead of a complete count-wheel or locking-plate there is only a portion of wheel L M, called the *rack*, turning on a

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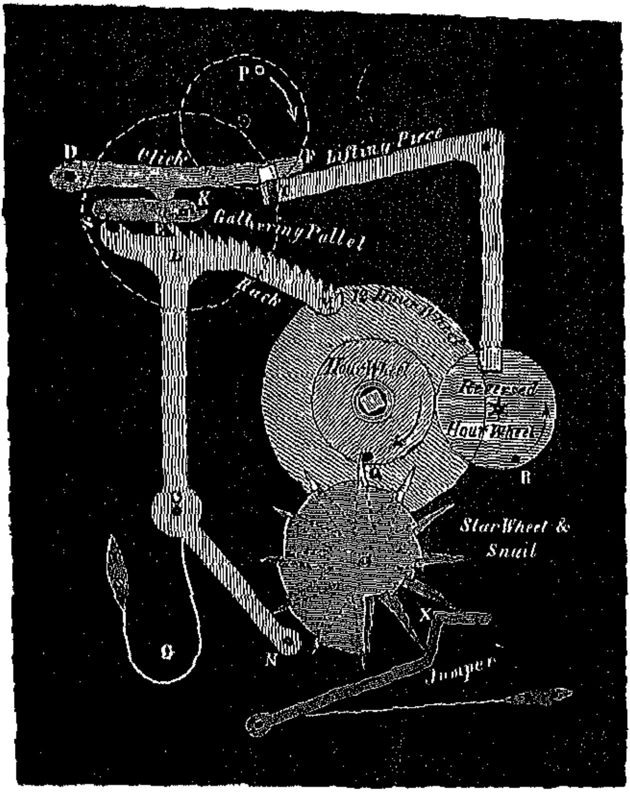
* Some clocks will be found to offer a resistance to being put back past the hour: if they do it cannot be helped; but the lifting piece ought to have had its end twisted so that the pin on the reversed hour wheel can pass the wrong way by pushing it aside. If a clock is put back between warning and striking it will strike: this does not signify in an English clock; but it will make any of the foreign clocks, which all have the locking-plate movement, strike wrong, and therefore must not be done.



centre O, and having 13 or 14 ratchett shaped teeth on it. Another radius O N of this fragment of a wheel has a pin N set upon it; and on a wheel called the *star wheel,* which will be described presently and turns in 12 hours, there is fixed a graduated *snail* with 12 steps in it, such that when the hour hand points to 5 for instance the pin N can fall against the 5th step in the snail to such a depth that the rack can fall through the space of 5 of the teeth. The rack has a click D E, set on a stud at D, which will hold the teeth in any given place, a spring G pressing the rack towards the left hand. The arm D E of the click is prolonged to F, and there rests upon the lifting piece, which is the same as before, and has a stop T projecting backwards through a wide hole in the clock frame, and so placed that when the lifting piece is down in its ordinary position, the pin P in the third wheel of the striking train can clear the stop T, but when it is raised it will stop the pin and consequently the train. When the clock gives warning, the pin R in the reversed hour wheel raises the lifting piece as before, which lifts the click, which lets the rack fall back as far as the snail allows it to go.

Over the rack there is a sort of hook K, which is in fact a pinion with one tooth, set upon the projecting arbor of the second wheel, (*i.e.* the one above the striking wheel), and at every revolution of that wheel, and therefore at every stroke of the hammer, it takes up the teeth of the rack one after another, and it is therefore called the *gathering piece* or *pallet*. When the clock is to strike, the lifting piece is let fall, which sets the pin P at liberty, and also lets the click fall on to the rack so as to be ready to catch the teeth and hold them as the gathering pallet gathers them up. After the pallet has taken up the last tooth, its tail, which is on the opposite side to the hook, falls upon a pin S at the end of the rack, and is thereby stopped from turning any farther, which of course stop the train.

91. If the clock is to be capable of repeating the las hour struck when required, the click F E D is prolonge

backwards and has a string put to it which comes through the clock case, and when it is pulled the clock will strike. But if the string is let go too quickly the click will catch the rack before it has fallen far enough, and the clock will strike too few; and if it is not let go quickly enough the click will not catch the rack at the first stroke, and it will strike too many. Therefore the string ought to be put to the lifting piece, instead of the click, which can be done just as easily, though I have never seen it so done. If you find on pulling the string that the clock won't strike, it is between warning and striking, and if you leave it alone it will strike of itself in a few minutes.

92. The star wheel, of which the construction is evident from the drawing, is turned $\frac{1}{12}$th round at some time in every hour (it should be done before the work of the lifting begins, that the clock may not have too much to do at once) by means of a pin Q on the hour wheel catching one of its *rays*. The pin does not indeed carry it through the whole distance it has to move, for by the time it has got about half way the ray at X in the drawing will have reached the angle of the thing called the *jumper*, sliding up its left hand inclined plane, and as soon as the point of the ray passes the angle, the jumper, being pressed upon by a spring, will do the rest of the work and drive the ray still farther forward by means of the right hand inclined plane. The jumper also acts as a click to keep the star wheel steady; a common click would not do, because it would not allow you to put the clock back, whereas this one will allow the rays to pass up either of the inclined planes. In the commoner kind of clocks this

star-wheel is dispensed with, and the snail is set upon the twelve hour wheel (in which case it must be reversed); indeed the only use of the star-wheel is to relieve that large twelve hour wheel arbor or pipe of the additional weight of the snail; and if that pipe were reduced to a moderate size and the twelve hour wheel driven directly by the train, as described in § 87, the weight of the snail might be disregarded.

93. Some clocks are so made that by turning a little hand which is placed above the dial the clock can either be made to remain *silent*, or be allowed to *strike*. This hand is so connected with the lifting piece that when it is turned to 'silent' it pulls the lifting piece out of the way of the pin in the hour wheel by drawing its arbor forward, the pivots being made long enough for that purpose; and when turned to 'strike' it pushes the arbor back again. Sometimes the striking is prevented by bringing a stop of some kind close up behind the pin S or some other pin set upon the rack, which prevents it from falling when the click is lifted, and so the gathering pallet cannot get past the stop S. This way is more simple than the other, but the other has this advantage that the clock can be made ordinarily silent, and yet it will strike whenever the above-mentioned string is pulled.

I have seen a third way used, viz: the train stopped by a hook or pin pushed into the way of the fly. This is a most blundering way of doing it; for, as it does not prevent the rack from falling, the clock is almost certain to stop between 12 and 1 o'clock, from not having force enough to drive the deep step in the snail past the pin N in the rack tail, even if it is made with a bevelled edge for the purpose. In fact the clock in which I saw it had so stopped, and I was told it had frequently stopped before, nobody knew why. I relieved it from the difficulty in future by taking away the 'silent' stop altogether. In a clock with the locking-plate movement however, this plan would answer perfectly, and is more simple than any other; and probably the maker of this clock had borrowed the plan from an old locking plate clock, not recollecting the difference.

94. It is merely a matter of taste whether a clock is made to strike on a bell, or on one of the spiral steel springs of a very deep note that have lately come into use. Perhaps in a room the spring has a more agreeable sound; but they are not heard so far as a bell, and at a distance they have a thin sound, very unlike what they pretend to imitate, a heavy church bell; and therefore for a clock to stand in a hall and strike for the whole house, a bell is certainly the best.

QUARTERS.

95. House clocks are occasionally made to strike quarters. The machinery for that purpose is the same as for striking the hours, if we suppose two hammers to be put in the place of one, and an additional set of pins on the striking wheel to raise them. If they are what are called *ding-dong* quarters, on two bells, this wheel may be made exactly like the hour striking wheel, only with two sets of pins set on its opposite sides so as to raise the two hammers alternately. But if there are four or more bells, the rim of

the striking wheel is spread out so as to form a *chime barrel*, with pins sticking out of it like the barrel of a musical box, and these pins raise the hammers successively, which are all set on one axis. I may here remind clockmakers (as I have found it necessary to do so before) that though the repeating movement may be used for the quarters as well as the hour, when the second, third, and fourth quarters are only the first quarter so many times repeated, yet when the tunes or changes are different the locking plate ought to be used; for if the repeating plan is used and one quarter gets struck wrong or stopped, it throws the whole of the tunes into confusion, the clock playing at the next quarter the right *number* of changes, but the wrong *order*, that is, a piece of the tune of one quarter, and a piece of another; whereas if the locking plate is used the right tunes will always accompany the right number of changes, and any person will hear directly not only that they are wrong, but *how* they are wrong, and that they merely want striking by hand once or more to bring them right, which it is much more difficult for an unskilful person to ascertain when the tunes are wrong but the number right. The work for connecting the repeating quarter movement with the hour striking part is also more complicated than that of the locking plate, which is remarkably simple. But as quarters are so much more rarely put to house clocks than to turret clocks, I shall reserve the description of the mode of connecting them with the other parts of the clock, as well as some other matters belonging to them, for the chapter on church clocks.

96. Small spring clocks are occasionally made to strike

the quarters only when they are wanted, as in the night, and to strike them *after* striking the preceding hour, just as repeating watches do. In this case, the repeating part is not wound up periodically as in a common clock which strikes quarters; but by pulling a string or pushing in the handle of the watch, you wind up a barrel containing a main-spring, which, when you let it go again, works the striking movement in the usual way, according to the position given to the rack or locking-plate by the wheels of the going train. Repeating watches are rarely, if ever, made in England, or at least by English workmen; and from the quantity of work that has to be put in a small compass they seldom go very well. For this purpose a small clock is much better; and such clocks are usually now made portable, that is with a balance instead of a pendulum, and go by the name of *carriage clocks*, and consequently they possess the advantage of being secure against the disturbances of housemaids. I shall have to mention them again in the next chapter.

ALARUMS.

97. If you take the pendulum off a clock with a recoil escapement, you will hear it beat about as quickly as the bell is struck in an alarum; and the striking there takes place in the same way as if a double hammer were put on the end of the crutch of a recoil escapement, just long enough for one end of the hammer to reach the inside of a bell at one extremity of the beat, and the other end at the other extremity. The manner of letting it off I shall describe presently; but

first it may be asked by an observant person, how it happens that such a small weight as that of an alarum, falling only a few inches, is able to strike such a vast number of blows, when the striking part requires a weight of 10 or 12 lbs. to strike so few as it does. The reason is this: the common striking weight has to raise the hammer against a strong spring; and the force with which it strikes the bell depends upon the force of that spring, and the distance it is bent; but in an alarum, the hammer is merely thrown from side to side by the action of the alarum weight, which has consequently nothing to overcome but the friction; and the velocity of the striking depends upon the proportion between the moment of inertia of the hammer and the momentum (or product of the weight and the fall) of the alarum weight. An attempt appears to have been made to produce a common striking part on this principle, but without success, because in that way it cannot strike with both force enough and slowness enough to be distinct.

98. But an alarum is wanted to let off, not always at the same time, but at an arbitrary time. For this purpose, all we have to do is to make the letting-off pin moveable on the wheel which carries it. If the common letting-off pin were made moveable upon the hour-wheel, we might make the clock strike when the long hand is at 50 m. instead of 60 m. And in like manner, if we put a letting-off pin for the alarum on a cap, or *key*, which fits tightly on to the socket of the 12-hour wheel, we can make it let off with as much accuracy as is required at any portion of the twelve hours we please. This key, which carries the pin, has its socket prolonged forward, so as to carry a small dial or hour circle under the

hour hand, which always travels round with it; but the key does not fit so tightly that it cannot be moved by the hand so as to make a pointer in the hour hand point to any time we like on the alarum dial; and then it will let off at the time so indicated. There is no occasion for any stopping apparatus beyond a single lifting piece, and a pin in the striking barrel, which rests against the stop on the lifting piece when it is not raised high enough to let the alarum go. The string of the weight is attached to a wheel exactly like a recoil scape-wheel, either of the crown wheel or the plain kind, and when it is let off it runs till it is down. Of course it must not be wound up until within twelve hours of the time when it is intended to strike.

THE WATCHMAN'S CLOCK.

90. This is mentioned incidentally in the parliamentary papers respecting the great clock for the new Palace, as being the invention of Mr. Whitehurst, of Derby. It is otherwise called the tell-tale clock, its object being to watch watchmen; whose tendency to sleep, like other men, in the night, had caused buildings protected by them to be considered less secure than those which are only protected by the ordinary precautions of mankind before they go to bed. In the watchman's clock there are pins sticking out round the dial, one for every quarter of an hour; and the duty of the watchman, in order to testify his own vigilance, is to go to the clock every quarter of an hour, and push in the proper pin, which only admits of being so treated for a few minutes: consequently, if in the morning any pin is found

sticking out, it indicates that the watchman was absent, in body or mind, at the corresponding time. There is a clock of this kind, on an improved plan, lately put up in one of the lobbies of the House of Commons. The face and pins are not open but inclosed behind a glass, and there is a handle at a convenient place outside the clock case, which communicates with a small lever standing over a part of the circle in which the pins move; and as the pins are carried round in a sort of a moveable dial, it is evident that pulling the handle when any particular pin is under the lever, it may be easily made to push that pin in, and can do so at no other time. In fact, if the lever ended in a pencil, and the moveable dial carried a rim of paper set round the figures, pulling the handle would make a mark upon the paper, showing exactly the time at which it was done. But the paper would want renewing continually, and the pins do not, but are made to pass over an inclined plane at their back in another part of their journey (performed after the hour of inspection), and so to push themselves out again: for this purpose it is most convenient to make the revolving dial to contain 24 hours, so that there may be time enough in the morning to examine the pins before they are replaced by the inclined plane.

ELECTRICAL CLOCKS.

100. If the pallets of a clock, instead of being worked by a pendulum, are attracted by pieces of soft iron, magnetized alternately by means of an electrical communication with the pallets of another clock, as they move to each side, or with the teeth of the scape-wheel successively, the two

clocks will evidently go exactly together. Not only this, but if you take off the weight as well as the pendulum, and move the pallets of a recoil escapement backwards and forwards, they will drive the scape-wheel instead of letting it escape, only they will move it, and consequently the hands, the wrong way; and, therefore, if the scape-wheel and pallets are reversed, they will drive the hands the right way. Instead of two magnets, one is sufficient, if the pallets are drawn one way by a small weight or a spring, and the other way by the magnet. This is the ordinary form of what are called electrical clocks.

101. But still further, the whole train of the clock may be dispensed with, except the dial wheels, by making the communication take place at longer intervals, such as every half minute. The wheel of the minute hand would then require 60 ratchett-shaped teeth, and a pair of large pallets to be put over it in the same way as the recoil pallets over a common scape-wheel; and at each beat the wheel would move through the space of half a tooth. A click should in any case be added to secure the wheel from slipping back at the moment of escape. The advantage of a minute-hand moving a visible space at intervals, such as half a minute, will be pointed out under the head of 'turret-clock remontoires,' § 172.

102. Another way in which this may be done, is to let the dial work be driven by a weight or spring, wound up just like a common clock, and make the electricity let it off instead of driving it. This method is peculiarly adapted to clocks with large faces and heavy hands; for in this way a dial, or any number of dials, of any size might be worked by

an escapement and train no larger than that of a common astronomical clock. The only objection to it is the difficulty of keeping a galvanic electrical machine in perfect action, so that you can depend upon a beat never missing; for it not only requires some attention to the galvanic trough, but a small particle of dirt on the rim of the wheel, which is divided into conducting and non-conducting spaces, sometimes interferes with the contact. Mr. Dent had an electrical dial, of the first construction just now described, going for some time in his shop, but he found it required constant attention to prevent it failing in this way.

103. When, on the other hand, a large and strong clock is employed to drive a number of other clocks, *magnetic* electricity may be used, the large clock by its own force pulling or rather sliding a strong permanent magnet out of contact with its *armature* at the proper intervals. Mr. Dent also kept a dial of this kind going for some time, making a small turret-clock movement work the magnet; and this experiment answered perfectly. Of course the clock which has to do this extra work should have some provision to prevent the inequalities of force produced by it from reaching the pendulum. It will be seen how this is to be done when we consider the subject of turret-clock remontoires. This general explanation of electrical clocks may be interesting to those who have read in the parliamentary papers on the subject, that it is proposed to have an electrical communication between the great clock at Westminster and the Observatory at Greenwich, and perhaps also to make it work the small clocks in various parts of the building.

104. Now that the very convenient practice of setting

all the clocks in the kingdom to Greenwich instead of local time is becoming general, it would be by no means an useless employment of the electric telegraph to send the exact time at a certain hour every day or every week to all the telegraph stations on the various lines of railway. The whole kingdom would thus have the advantage of an indication of the time as perfect as that afforded by the ball on the top of the Observatory at Greenwich, which is dropped every day exactly at one o'clock. Whereas at present, the time can only be obtained in places where there is not a good meridian instrument by the tradition of travellers or railway guards, which is equivalent to saying that it cannot be obtained at all with accuracy. I have sometimes found a difference of five minutes between the time of the public clocks in large towns less than 100 miles apart, and not admitting of the excuse that it was the difference of local time, because, unfortunately, it has been occasionally the wrong way, *i. e.* the clock in the west has been faster than the clock in the east.

MUSICAL CLOCKS AND CHIMES.

105. These are merely common clocks, which let off a musical box, or a small organ driven by a weight, or a chime barrel in a church, in the same way as an ordinary striking part. A chime barrel is exactly the same as the barrel I before mentioned for playing a tune at the quarters, only much longer, having to play a longer tune and on at least eight bells, to each of which there are generally two hammers, because when a note has to be repeated quickly, one hammer could not fall and rise again quickly enough.

A musical box is the same in principle, only the music is in the springs raised by the pins on the chime barrel, instead of those springs being levers working hammers that strike on bells; and accordingly musical boxes are generally repaired by watchmakers. Organs involve other considerations besides those of clockmaking, though many of the German clockmakers repair these clock organs; indeed they are hardly ever applied except to German clocks.

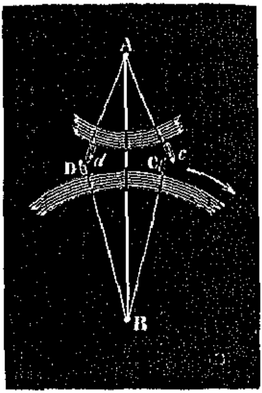
Clocks are occasionally made to perform other feats, which I do not consider as properly belonging to the art of horology, but merely toys; and it is true of clocks, as of human beings, that if they profess to do a great many things, they seldom do them well. This remark, of course, does not apply to church clocks with chimes, which are on a large scale, and can have ample power and space to do the additional work.

TEETH OF WHEELS.

106. The theory of wheel-cutting does not belong more to clock-work than to any other machinery in which wheels are used, and it is too large a subject to enter into fully here. But it may be useful to make a few general remarks upon it, and I must refer the reader to other works, such as 'Camus on the Teeth of Wheels,' 'Willis's Principles of Machinery,' &c., for the geometrical investigations by which these results are obtained.

First, it is evident that the more teeth any two wheels have which are to work together, the less friction there will be, and the less it will signify whether the teeth are acculately cut of the right shape. For if the teeth were infinite in number, and therefore infinitely small, there would be no sliding friction at all, and the wheels would merely roll upon each other; and on the other hand, the fewer the teeth of each wheel are, the farther they have to slide along the teeth of the other wheel. And as the same *proportion* must be kept between the wheels and pinions of a clock train, whatever the actual numbers are, the number of teeth or leaves in the pinions is at once an indication of the degree of labour which has been expended on that portion of the clock. In the best astronomical clocks no pinion has less than twelve leaves, and sometimes as many as sixteen. In the striking part of clocks, there is no need of the same high numbers, because the uniformity, or amount of the force of the train, is of no great consequence (within reasonable limits) so long as it is always sufficient to raise the hammer.

107. Another thing to be remarked in clock-work is, that the pinions are all driven by the wheels, except the pinion of the dial-work which drives the 12-hour wheel, and the pinion which drives the locking-plate when it is not placed upon the great wheel of the striking part; whereas in machinery for raising heavy weights, the pinions generally drive the wheels. And this is of consequence for the following reason. When two wheels act together, the teeth which are in contact may happen to be either entirely on one side of the line which joins the centres of the two wheels, or on the other, or on both sides. If the teeth have passed that line before they come into contact, the action is said to be *after* or *behind the line of centres;* and *vice versâ.*



In this figure, D, C, represent two teeth of the driving wheel, and *d*, *c*, two corresponding teeth of the driven wheel. Now, although they are here represented as inclined to each other at the same angle in each case, yet any one must see at once that the friction between C and *c*, after the line of centres, is very much less than between D and *d*, before the line of centres: no degree of friction (short of adhesive friction) could prevent C from driving *c*, if force enough is applied to it; whereas if the point of contact of D and *d* is a good way from the line of centres, and the surface of D rough, a great force applied to the driving wheel might merely drive the point of the tooth *d* into the side of the tooth D. The difference between drawing a walking-stick along the ground after you and pushing it before you is an illustration of the difference between friction after the line of centres and before; and a very moderate degree of roughness will make it impossible to push it if it makes a large angle with the ground. It is evident therefore that machinery will go much more easily when the teeth of the wheels are so arranged that all the wheels are driven behind the respective lines of centres. Now it may be shown geometrically, that with teeth of the common form a wheel cannot drive a pinion with leaves of sensible thickness without any friction before the line of centres, if the pinion has less than eleven leaves. This, therefore, is another reason for using no pinions in delicate clocks with less than twelve

eleven being an inconvenient number, and of course
her the number the better.

3. There is, however, a kind of pinion, in which
driven, but just the opposite when *driving*, for which
re they are unfit) the action will always be after the
centres, however few its leaves may be: it is a pinion
h the leaves, instead of being radial or of the leaf-
are round pins set in a ring round the axis; and
eir appearance, these are called *lantern* or *box pinions.*
drawn the pinion of the scape-wheel in p. 79 as a
pinion. Of course, in these as in all other pinions,
ill be less friction with many leaves than with few;
atever friction there is will be entirely of the more
ss kind. The Dutch clocks always have these pinions,
are merely bits of wire stuck into wooden arbors, and
the reason why they will go with an amount of dirt
ould completely stop a clock with the common
, and their pinions are the last thing in the clock
r out. The French have also long used them in
urret-clocks, and it is stated in one of the parlia-
y papers, by Mr. Dent, that they have been found to
o signs of wearing after sixty years: whereas in
made wholly with teeth, if not very accurately made,
ions and the wheels that work them will be found to
orn themselves out of shape in a few years. I have
report made by a man who was sent to examine a
clock, made by a London maker, only fourteen years
which he stated that he found the pinions had
lready twice shifted to get a new bearing for the
nd that they were now thoroughly worn out. Of

course this was an extreme case; but it would not have happened with lantern pinions and equally ill-cut teeth, because they would only have had the more moderate friction of the action after the line of centres.

109. Another great advantage of these pinions is, that there is considerable risk of spoiling solid pinions, especially large ones, in hardening them. I have seen a large pinion with half the leaves flown completely off in hardening; and of course the risk of this adds to the expense of those that are sound, and also very often causes them not to be hardened at all, which is just one of those things for which you can have no security except the character of the maker. Whereas the lantern or box pinions never break, and are made merely by driving hard steel wire pins into the holes in the box, which are bored with great quickness and accuracy by a sliding drill and a dividing engine. Consequently, besides their other advantages, these pinions are probably, and when they are of large size, certainly, cheaper than solid steel pinions, which require cutting, hardening, and polishing, and often break when they are done.

It must be remembered by those who are not used to them, that lantern pinions require the teeth that drive them to be cut of a different shape from teeth that drive common leaves, the teeth that drive the common leaves being epicycloids traced by a circle of *half* the radius of the pinion rolling upon the driving wheel; while the teeth to drive pins are epicycloids traced by a circle of the *same* size as the pinion itself. No doubt very few teeth, especially in small clocks, are really epicycloidal, but some portion of circular arcs pretty nearly coinciding for a short distance with an epicycloid; and where the teeth are numerous, and therefore small, there is very little difference. But when the teeth are large, the difference is sensible, and there seems no reason why the *cutters* of the teeth of large wheels should not be made of the proper shape more frequently than they are. It ought, moreover, to be remarked that, whether the teeth are circular or epicycloidal, the practice of *topping*, or turning off the tops of the teeth by way of correcting the *depths* is entirely wrong, because it takes off the most curved part of the teeth. If the teeth are cut right, and the depth is found to be wrong, the centres are wrongly placed, and should be altered, not the teeth, which are innocent.

110. It is not indeed quite true that the action of a lantern pinion begins when the acting side, but when the *centre* of each pin, is on the line of centres; and therefore the action is not so completely after the line of centres as a leaved pinion of twelve or more teeth. But practically this is no objection to their use; first, because none but the most expensive clocks have pinions of twelve, and it is not in clocks of that kind that there is much to be gained (as regards friction) by using these pinions; and secondly, the advantages of easy construction would still remain on the side of the lantern pinions, especially when they are large. The scape-wheel of the Exchange clock is made in this way, although the pins are leaf-shaped, because it has twenty of them, and is therefore so large that it was found impossible to harden a solid pinion properly. For the same reason Mr. Vulliamy makes his large pinions of gun-metal, as hard as it can safely be used, which however is much softer than hard steel, or even cast iron. Thirdly, when you come to pinions of high

numbers, the angle corresponding to half the thickness of the pin is so small, that it is of no consequence whether the action begins that small distance before the line of centres, or exactly at the line, for the nearer you come to that line, the less friction any deviation from it produces; and therefore making the pins of the Exchange scape-wheel of the leaf-shape instead of round was quite an unnecessary and very expensive refinement; and Mr. Dent now makes all the pinions of the going trains of his turret-clocks lantern pinions, with round and hard steel wire pins, and the ease and smoothness of their motion is remarkable, even in a case where it was necessary to use a pinion as low as seven, which will be described in § 177.

END OF CHAPTER I.

Chapter II.

ON WATCHES AND CHRONOMETERS.

111. I have already said that the only mechanical difference between a watch and a clock, is that a watch will go in any position, but a clock only in one; for although timepieces in cases like small bracket-clocks, only with a balance instead of a pendulum, are popularly called clocks, they are really watches, differing only from common watches in their size, and in the balance being set horizontal, or in a plane perpendicular to the planes of the rest of the wheels. Such clocks have of course the advantage of being portable, and are called *carriage clocks*. But unless they have compensated balances, they are much more affected by changes of temperature than pendulum clocks, or watches, which are kept at a pretty uniform temperature by being carried in the pocket, as will be explained in § 124.

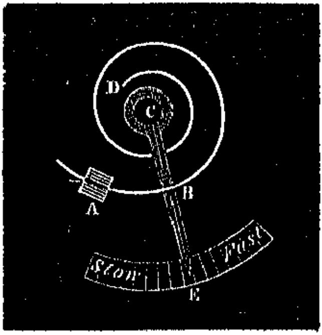
112. If you take a common spring clock, with its wheels and escapement arranged exactly like that of which a drawing was given at p. 49, and instead of the crutch for the pendulum put a wheel of the nature of a fly-wheel, this will be very nearly a watch. Not quite, however; for it still differs from a watch in this, that the fly-wheel or balance has no spring, and so its vibrations will depend only upon its

own moment of inertia, *and the force of the train.* And this last dependence is just what we want to get rid of, or to compensate in such a way that comparatively large vibrations of the balance shall be performed in the same time as smaller ones. Dr. Hooke ascertained, among his numerous other discoveries and inventions, that the vibrations of a spring in large or small arcs are very nearly isochronous. The reason of which is that the force with which a spring endeavours to resume its position generally varies as the angle through which it is bent, with the exception before mentioned in § 80; and a body acted upon by such a force as this (as a pendulum moving in a cycloid is) must oscillate through any distance in the same time. Consequently if one end of a spiral spring is fixed to the frame in which the balance-arbor turns, and the other to the balance itself, in such a position that when the spring is at rest the pallets stand half way between each beat, and the balance is set in motion, it will go on vibrating in very nearly the same time, whether the force of the escapement drives it through a small arc or a large one. In fact, with pallets of this kind the watch will set itself going, because a tooth of the scape-wheel must always be pushing against one or other of the pallets, and the spring offering scarcely any resistance in the neutral position (unlike a heavy pendulum) the force of the escapement is sufficient to move the balance through the angle of escape; and having once begun, it will of course go on. Hence it is that with most escapements a watch cannot be stopped, if it is clean and in good order; for as the impulse is generally given at the neutral position of the spring (as it ought to be, for the same reason as in clocks), the force requisite to give the impulse is generally sufficient to start the balance. The same thing happens in a clock when you take the pendulum off, and the escapement has only the slight weight of the crutch to move.

113. The spiral springs used for escapements are of two kinds; the common one lying all in one plane, and the other, used for chronometers, in which size is not sacrificed to elegance, is like a wire wrapped round a cylinder, as the string of a clock is wrapped round the barrel; since this is found to be the best form of the two, perhaps on account of every ring (so to speak) of the spiral having the same radius, and the spring acting therefore more uniformly.

114. The kind of watch that I have been describing is the old *vertical* watch, so called because the scape-wheel stands vertically when the other wheels are horizontal, or the watch is laid flat. This kind of escapement, as before mentioned, like the common recoil escapement in clocks with anchor pallets, loses as the arc of vibration decreases.

REGULATION OF WATCHES.



115. The mode of regulating this and all watches is by altering the fixed point of the spiral spring, so as to make the acting part of it shorter or longer, and therefore faster or slower in its vibrations. This is done as follows. A B D is the

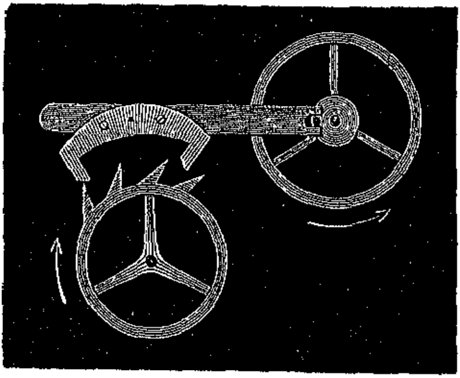
spring, or rather a portion of it, as I have stopped it at D to avoid confusion. The outer end of it is pinned into a cock set on the frame at A. The pointer C B E turns on an annular or hollow pivot at C, the hole being left in its centre for the arbor of the balance, which is called the *verge*, to go through. At B there are two small pins close together, between which the spring is passed, and which therefore determine the point from which it begins to bend. Therefore as the pointer or *regulator* C B E is moved towards the right in this drawing, it makes the spring vibrate faster, and to the left, slower; and this is done without affecting the neutral position of the spring. If the watch still goes too slow, when the regulator is moved to the right as far as it can go, the spring has to be taken out and shortened by putting the outer end farther through A and drawing the inner end farther out through the other cock by which it is pinned to the balance; for as a given angle corresponds to a smaller length at the inner end of the spiral than at the outer, the spring will on the whole be shortened by this operation, while the neutral position of it with regard to the balance remains the same. In order to alter the length of a cylindrical spiral spring, either its curvature must be altered a little or the point at which it is attached to the balance. But, in fact, chronometers are not regulated in this way, but by altering the inertia of the balance by screws with heavy heads, called *timing screws.* The vertical escapement is only now used for the commonest watches, both on account of the thickness it requires, and its inferiority to other escapements.

LEVER ESCAPEMENT.

116. The escapement which is far the most frequent in good English watches is the *lever escapement*, or, as it used to be called, the *detached lever*, to distinguish it from another form of it, now disused, called the *rack lever*. If you put a rack, or a few teeth of a wheel, of which the pallet arbor would be the centre, on the end of the crutch of a clock dead escapement, and let this rack work a pinion set on the verge of a balance, such as I have just now described, the vibration of the balance would cause the pallets to move as they do under the influence of a pendulum. And this was the rack-lever movement.

117. It was however liable to stop if the balance was accidentally stopped at the neutral position, on account of the friction between the rack and the pinion; and moreover the lever or crutch and pallets were carried farther the farther the balance vibrated. This as we have seen cannot be helped with a pendulum, on account of the small angle which it moves through; but it can with a balance, since that moves through such a large angle that the arc described by a pin set a little distance from the verge will cut the arc described by the end the lever so as to include a very sensible depth between them. Consequently if the end of the lever merely has a nick in it, and the verge instead of being a complete pinion has one tooth or pin that will fit into the nick, the lever and pin will act together as a wheel and pinion for a short distance in the middle of the vibration, but as soon as the pin has got out of the nick the balance may turn as far as it pleases without moving or

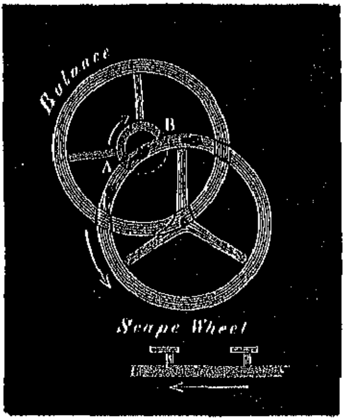
being even in contact with the lever; and when it returns the pin will go into the nick again and first move the dead part of the pallet off the tooth of the scape-wheel, and then receive the impulse and leave the opposite pallet with a tooth resting upon its dead part. Therefore this was called the *detached lever*, as the lever is detached from the balance except during the middle of the vibration. The pin is usually made of a jewel, and it works with so little friction that you can hardly (if at all) stop the watch, any more than a clock with a dead escapement when the pendulum is taken off. The pallets are also always made of jewels in good watches. In this drawing the balance is put beyond its real distance from the scape-wheel in order to show the other parts more plainly: it is exhibited at the middle of the impulse. The practical advantages of this movement are that it is not only a very good one, being like the dead escapement of a clock, and without the dead friction, which is very nearly removed by the detachment of the balance from the pallets, but it is moreover easy to make and safe to wear; and if the watch gets such a fall as to break the verge, which is always the first thing to break, it can be mended for a few shillings, the verge in this



escapement being nothing more than a plain arbor, which carries the pin set upon a small collar. Whereas in the two next escapements the verge itself is comparatively complicated, and expensive to make and mend.

HORIZONTAL ESCAPEMENT.

118. It is curious that this, which was invented by an English clockmaker, Graham, is the escapement put to nearly every foreign watch, whereas the rack lever, which was the foundation of the detached lever, the principal English escapement, appears to have been invented in France, though the detached lever was invented by Mudge, a famous chronometer maker here. There is nothing in clocks corresponding to this escapement, and it will be best understood at once from the drawing. The verge is spread out about its middle into a portion of a hollow cylinder, of which the section is shown at A B. The scape-wheel teeth are of the shape of a 'flat iron' set upon a pin, as shown in the second figure, and just long enough to be contained with the cylinder. A tooth is here represented as just escaping from the inside of the cylinder and giving the im-



pulse; for as the balance turns to the right* the sloped part of the cylinder at A comes up to the point of the tooth, and so the tooth in making its way out, gives an impulse to the balance; and then the next tooth strikes against the outside circular part at B, and rests on it until the balance turns the other way, and then that tooth makes its way into the cylinder giving an impulse in so doing. This escapement therefore is not detached, as a tooth is always pressing either upon the inside or the outside of the cylinder, and as in the common dead escapement, a tooth is always acting on the inside of one pallet or the outside of the other. This is not unlike the pin wheel dead escapement in this respect, that it is not very material that the teeth of the scape-wheel should be exactly at the same distance from each other, since they act successively. But is very unlike it in another respect, that it is very expensive to mend if broken.

One curious fact in this escapement is worth mentioning: it is found that the sharp teeth of the scape-wheel cut the cylinder less if they are made of steel than of brass. I have heard of no satisfactory way of accounting for this; and it seems that there is yet room for a good deal of discovery in the theory of the wear of two metals working together, in which several of the known facts are different from what were anticipated, especially the necessity for soft bearings, made only of block tin, which is nearly as soft as lead, for railway axles or *journals;* while on the other hand I understand that brass, and even gun-metal, is abaned for the bearings of lathe spindles in favour of cast- or steel. There is no doubt, however, that iron and l working together require fresh oil more frequently than s and steel; and brass scape-wheels are nearly always l for the dead escapement in clocks, and the lever pement and all others except the horizontal in watches, ch is just the one in which we should have expected the its of brass teeth to be worn out sooner than in any er, instead of wearing the hard cylinder.

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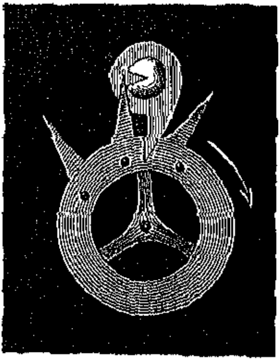
* Perhaps it may be as well to explain, that a wheel is said to turn to the right, when, if you took hold of it with your right hand in its natural position, you would turn your thumb to the right.

DUPLEX ESCAPEMENT.

110. The duplex escapement is so called because the pe-wheel has a double set of teeth: viz., a set of long th, which merely rest against verge of the balance except en they are escaping, and a of short teeth or pins to e the impulse at the time of ape. The long teeth are so de that their forward edge is adius of the scape-wheel and tangent to the small circle th a notch in it; consequently it circle or cylinder, which is a portion of the verge, can rn to the right, with no other effect upon the long teeth, an that the friction against them is rather greater as the ening of the notch passes, than when they are merely essing upon the cylinder; but as the cylinder is very nall, and the teeth long, and the notch narrow, this extra iction is very little. When the balance returns, the point the tooth falls into the notch, and goes along with it, and

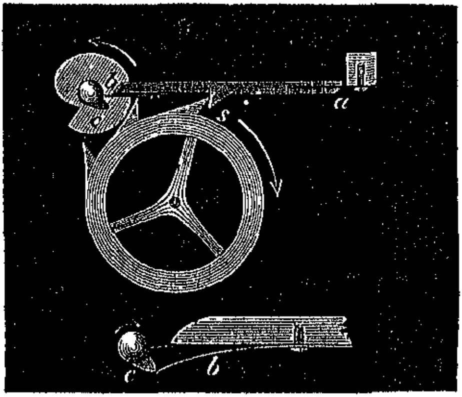


so escapes, and at the same time one of the pins catches the long tooth projecting from the verge, and gives the impulse.

It will be seen that the principle of this escapement is not unlike that modification of the dead escapement for clocks, which I suggested (45), and which if it can be made accurately enough with moderate care, ought to answer equally well; for here the dead friction is that of long teeth acting upon a cylinder of small radius, while the impulse is given by short teeth acting against a long radius. For this reason, and also from the action being so direct that it does not require oil, the duplex escapement is a very good one; but, as may be inferred from this description of it, it requires unusual care in making and putting together, and also in carrying about; for if, by an accidental twist of the watch, the balance should happen not to vibrate far enough to let the notch get past the long tooth, the escape cannot take place, and the balance loses its impulse for that vibration; and as it only receives an impulse at every alternate vibration, unlike the three preceding escapements, it will probably not recover itself and will stop. It is therefore unfit for ordinary wearers of watches, and above all for those who in winding up their watch turn it nearly as much as they do the key: a very mischievous practice with any good watch, as it deranges the arc of vibration for the whole time of winding up, and some time afterwards. It is not perhaps very easy to avoid it altogether with an ordinary key; and therefore I should recommend persons who have really good watches to get a key made with a straight wooden handle like a thickish pencil. You can then wind up your watch, keeping it quite steady, by a few twirls of this pencil between your finger and thumb, and in a quarter of the time that a common key takes. The watchmakers themselves always use these pencil keys.

CHRONOMETERS.

120. The perfection of all the watch escapements is that which has from its use acquired the name of the *chronometer* movement, but was originally called the *detached*, the balance being entirely detached from everything else except just at the time of action: in other words there is no dead friction; and moreover the impulse is given directly, and nearly at right angles to the line of centres of the balance and scape wheel, as in the duplex escapement, instead of obliquely as in the vertical, lever, and horizontal escapements; and therefore it is not subject to derangement by the variable state of the oil, as it requires none. The teeth of the scape-wheel, instead of resting against a verge, rest against a stop S set upon a lever *a b*. This lever having only to move through a very small angle is set upon a small and stiffish spring at *a* instead of a pivot, which allows it to move just as a pendulum spring does a pendulum. The other end of



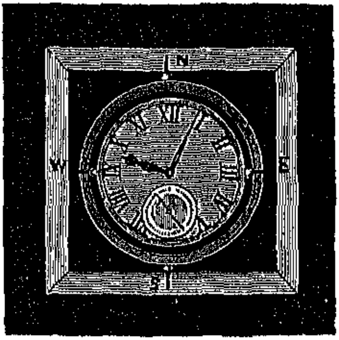
the lever has a weaker spring *b* also screwed to its inside (that is the side nearest the scape wheel) and projecting a little beyond its end. On the verge there is a small tooth or cog *c* which can pass the spring in the direction towards the scape wheel, by merely pushing it aside as shown in the enlarged drawing of that part, as it has room to bend in that direction; but in going the other way the spring cannot bend, and therefore the tooth *c* carries the lever with it, moving on its own spring *a*; and in so doing the stop S is pushed out of the way of the tooth of the scape wheel, which is therefore let go; and at that moment the long tooth or snail end attached to the verge (which corresponds exactly to that in the duplex escapement), comes into such a position that the tooth of the scape wheel catches it and gives the impulse.

It is evident that this also is an escapement that requires considerable care in making and using. However it is never applied to any but chronometers, or the very best watches, and those of considerable size, and persons who possess them are aware that they are instruments of a very different class from an ordinary watch. It is mentioned in the Encyclopædia Britannica that a maker of the name of Owen Robinson made use of long teeth for the stopping part, and short ones for the impulse, as in the duplex escapement, but the contrivance has not been generally adopted. Probably the friction of unlocking the common teeth is so small that the two sets of teeth were not worth the additional trouble, and the long teeth increased the inertia of the balance.

121. It may be observed that as the lever is not com-

terpoised, the work to be done in unlocking is different, according as the watch is placed vertically with the weight of the lever pressing towards the scape wheel, and therefore having to be lifted at unlocking, or the other way up, when the weight of the lever helps to unlock it, or horizontally, when the weight acts neither way. Consequently it is desirable to keep a chronometer always in one position; and that position is the horizontal one for another reason, which applies to several things besides chronometer balances.

If you take a small portable clock with a balance heavier than any watch balance, and lay it on its back or side, and observe the vibrations of the balance, you will see that they are much less than when the clock stands up, so that the balance is horizontal. The reason is that a pivot standing upright and with its point resting on a hard surface, and merely kept in its place by the hole in which it is placed both at the top and bottom, moves with much less friction than the same pivot set horizontally in circular pivot holes. For, however thin the pivot may be made, of course its point can always be made smaller, and in fact, if the wheel is light, it may approach indefinitely near to a point, in which case there would be no friction, at least none which the weight of the pivot and its wheel would augment, the lateral friction against the sides of the hole being independent of the weight resting on the vertical pivot. Ship chronometers are accordingly kept horizontal by being hung in *gimbals* (see next page), which are in fact an universal joint, the chronometer having two pivots E, W, which move in holes in a large ring having other pivots N, S, at right angles to E, W, which turn in holes in the sides of the box.



The fly of the striking part of very large clocks is in like manner sometimes placed with its axis vertical, being connected with the train by bevelled wheels, partly in order to avoid the friction on the pivots of such a heavy fly movingwith great velocity, and partly to save room.

122. Another remarkable application has lately been made of this principle of using vertical pivots; viz. in the ship compass. Everybody knows the common way of doing it, viz., fixing the *card* and *needle* upon a conical cap, or inverted cup, standing on the top of a sharp spike. This, of course, has very little friction, when merely revolving level; but then it is liable at sea to great disturbances which sometimes render it useless; and moreover these vertical oscillations soon wear the point blunt. Mr. Dent has therefore lately applied the chronometer suspension to compasses; that is, the axis goes right through the *card* like the axis or verge of a watch balance, and rests at the bottom on a jewel or hard piece of steel put under the pivot hole, and at the top in an ordinary pivot hole set in a frame above the card, the whole apparatus, as usual, being swung in gimbals in the same way as the chronometer just now described. There appear also to be several collateral advantages in this kind of suspension besides its steadiness; such as the power of making the compass as *sluggish* as you please

by means of an adjustable spring pressing against the side of the upper pivot, and the power of inverting the compass to ascertain the error of *collimation.* However, it would be out of place here to dwell at any length on the compass suspension, which is only introduced as an illustration of the principle of suspension of the marine chronometer.

I said just now that the lower pivot of this compass rests on a hard piece of steel or a jewel. In the escapement of all good watches, and in the best clocks, there are what are called *end-stops;* that is, the pivots are not kept in their place endways by their *shoulders,* but by stops, of metal in clocks, and jewels in watches, against which the pointed ends of the pivots rest, not of course tightly, but sufficiently close to allow only the necessary *shake* or freedom. The necessity of this freedom, both endways, and sideways, of all the pivots in clock and watch work, is one of the points in which it differs from common engineering; for in other machines there is generally force enough to spare, so that a slight degree of tightness in a pivot does not signify, especially if plenty of oil is used. But in the going part of a clock such an occurrence would probably stop it. Besides the end-stops, the pivot holes for the balance, and the scape-wheel, are made in jewels in good watches; and beyond these there appears to be no use in jewelled holes; and watches that are called jewelled in eight or ten holes are often inferior to those which are only jewelled in the four I have mentioned.

NEW STOP WATCH.

123. It requires some experience and quickness to note

the exact second at which any phenomenon takes place which you have to employ your eyes upon. Astronomers do it by looking at their clock at some given second, and then counting the beats from it by ear as they look through the telescope; and experienced persons can do this to a tenth of a second. But for the purpose of making this more easy to ordinary people, watches have been lately made with a large second-hand, carrying some colouring fluid on its end; and there is a small pin which you press with your finger at the moment when you observe the phenomenon, and this presses the point of the second-hand upon the dial, and so makes a mark, which you can afterwards examine at your leisure, and without the necessity of employing your attention on counting the seconds. The same thing used to be done by the pin stopping the watch when it was pressed, which of course made it wrong afterwards. In a stop watch, of either kind, you can only denote the time to that fraction of a second, which the scape-wheel happens to beat; and therefore a watch with a lever escapement will be better for this purpose than one with a detached or duplex movement, since in them the second-hand only moves at every alternate vibration of the balance.

In other respects watches differ so little from clocks in the principles of their construction, that it is unnecessary to say any further on that subject. But there still remains to be noticed a condition which is even more essential to the accuracy of their performance than to that of clocks. I mean the

COMPENSATION OF THE BALANCE.

124. The balance of a watch requires compensation much more than a pendulum, if it is to be exposed to such changes of temperature as chronometers are, though watches carried in the pocket are not subject to much variation of that kind, unless they are left exposed in cold nights. The variation in the elasticity of the spring, which affects in a small degree the vibration of a heavy pendulum whose time is mainly determined by gravity (65), affects a light balance whose time of vibration is mainly determined by the force of the spring a great deal more. I extract from a small pamphlet on compensation balances, published by Mr. Dent, the following results obtained from a glass disk as a balance, which was used for the experiment on account of the moment of inertia of such a disk being less affected by temperature than a metallic one.

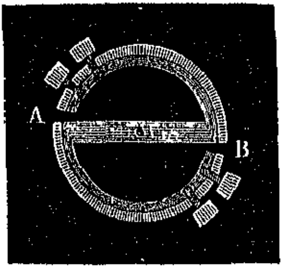
Temperature.	Vibrations in an hour.
32°	3605·7
66°	3598·2
100°	3589·7

(The proper number being 3600). Supposing, therefore, that the balance had been adjusted to go right at 32°, it would have lost 7·54 and 8·5 seconds respectively for the first and second increase of 34°, which is equal on the average to more than 3 *minutes* in the day; whereas we saw (57) that a common iron wire pendulum would only lose 10 *seconds* in a day, with about 1½ more for the spring, under such an increase of heat of 34°. And if a metal balance had been used instead of a glass one, the loss would have been still more, on account of its expansion. I believe it is not far from the truth to say that the effect of the expansion of the metal in a balance is as much less than that of the weakening of the spring, as the effect of the weakening of the spring is less than that of the expansion of the steel rod in a 1 sec. pendulum. Any body may easily satisfy himself that the variation in the elasticity of a watch-spring vastly exceeds in effect that of the spring of even a short pendulum, by putting a common watch and a bracket-clock with a pendulum together in a cold room in winter, and adjusting them (if necessary) till they go pretty well together; then shut them up in a hot room for a day, and you will see that the watch has been left several minutes behind by the clock, in consequence of the greater effect of the heat upon the balance spring than upon the pendulum spring; for as far as the expansion of the metals is concerned, the balance and the pendulum rod will expand about equally.

125. The difference in the amount of compensation required by a balance and a pendulum is so great, that it cannot be effected exactly in the same way, though all the methods that have been invented depend upon the same principle, of making small weights attached to the balance approach nearer to the centre as the heat increases, so as to diminish the moment of inertia, or the resistance to the force of the spring.

It is true of a balance, as of a pendulum, that if it were composed of rods or spokes without weight and a rim consisting of a single heavy line, or even a line with weight in only one point, the time of its revolution would depend (the force being the same) solely on the square of the radius of the rim. But as the mere expansion of the wheel itself produces a small effect compared with the decrease of force in the spring, it is evident that we must have some more violent method than the *straight forward* expansion of one metal over that of another, which will do in a pendulum, to produce the requisite effect in a balance. And this effect is produced accordingly by the *curvilinear* expansion of one metal upon another.

If you fasten together tightly, as by soldering, a bar of iron and of brass, and heat them, the brass expanding more than the iron will evidently bend the iron inwards. The way, therefore in which a compensation balance is made is this. A ring of steel is made with a bar across the middle; outside the ring is cast another ring of brass in such a way as firmly to adhere to the steel, in fact to be brazed to it; this ring is then filed up to the proper size, and then a broadish cut is made through both rings at each of the corners A, B; and finally a few screws with heavy heads are set in various places near the end of each portion of the cut ring. Consequently, as the heat diminishes the force of the spring, it expands the outside brass curves more than the inside steel ones, and so their ends, with the additional weight of the screws, bend inwards towards the centre of the balance, and its moment of inertia is diminished. The proper adjustment of these screws is, as may be supposed, a very delicate operation, and requires a great



many trials at different temperatures, and can therefore only be done in winter, or by means of freezing mixtures; and is consequently very expensive. And many watches with compensation balances are sold, which have never been adjusted at all, and nobody can tell by merely looking at them whether they have or not. They may be somewhat better than completely uncompensated balances, as the screws have probably been put in according to the common rules for a first approximation; but this is a matter in which no security can be had except the reputation of the vendor, unless he will allow the watch to be taken away and tried in different temperatures: any person, of ordinary observation, who has the means of resorting to a good clock can easily try whether the compensation is tolerably complete, or is over-done, as it sometimes is.

A similar contrivance has been applied to compensate a pendulum: two compound rods of this kind, with the brass side downwards, being made to project from the bob, and carry balls at their ends, which therefore rise as the bob falls and the brass expands. They have, however, never come into general use, and all such projections from a pendulum are objectionable on account of their tendency to twist if not placed exactly in the plane of vibration; and it would be unsafe to trust to a compensation of this sort without actual trial, which would make it at least as expensive as a zinc compensation; and on a large scale the compound bars would probably split themselves asunder instead of bending.

SECONDARY COMPENSATION.

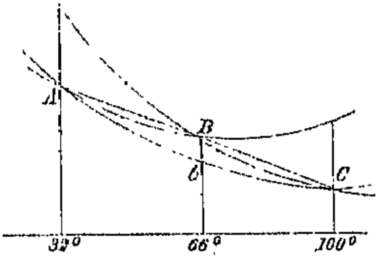
126. Still however the compensation is not completely

effected in this way. It has been found that if it is adjusted for two extreme temperatures, such as 32° and 100°, the watch will gain at mean temperatures, and if adjusted for mean it will lose at extreme temperatures. The reason is this. The force of the spring is ascertained to vary as the temperature; but the isochronism at different temperatures depends upon the ratio of the force of the spring to the inertia of the balance remaining the same, just as the time of a pendulum depends upon the ratio of the force of gravity to the radius of oscillation. Now by the ordinary method of compensation the weights approach the centre at a rate nearly proportionate to that of the increase of temperature, in fact rather more rapidly at low temperatures than high ones, which is just the reverse of what is wanted. For the inertia of the balance depends on the *square* of the distance of the weights from the centre; and therefore in order that it may always bear the same proportion to the force of the spring, the distance of the weights ought to vary more rapidly when they are near the centre than when they are far from it, that is more rapidly at high temperatures than at low ones.

To persons accustomed to mathematical formulæ the nature of this result will be clearly exhibited by observing that if r be the distance of the weights M (which for convenience we may suppose to be the whole mass of the balance) from the centre, the new moment of inertia, for an increase of temperature which causes an increase of r which we may call dr, will be $M\left(r^2+2\,rdr+dr^2\right)$; or the ratio of the new inertia to the old will be $1+\frac{2\,dr}{r}+\left(\frac{dr}{r}\right)^2$.

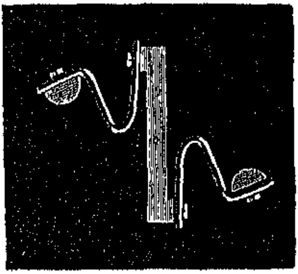
The reader may remember that in the case of compensated pendulums we neglected the quantity corresponding to $\left(\frac{dr}{r}\right)^2$ because of its smallness; but the compensation required for a balance spring is so much greater than that required for the expansion of a pendulum rod, that the effect of the term $\left(\frac{dr}{r}\right)^2$ now becomes sensible; for, as was stated before, the object of these compound bars of balances is to make r vary much more rapidly than it could do if the metals acted only by their direct expansion. And it is this term $\left(\frac{dr}{r}\right)^2$ which renders necessary what is called the *secondary compensation,* which is of course a great deal smaller than the primary one which is represented by $\frac{2\,dr}{r}$, but still is large enough to require a special contrivance in very accurate chronometers.

127. Or to adopt the illustration given in the pamphlet I have referred to, the variation in the force of the spring may be represented by a straight line A B C inclined to the straight line of temperature at an angle representing the ratio at which the primary compensation must advance; whereas the variation in the inertia can only be represented by a curve such as A b C, which can be made to coincide with the straight line at any two points



we please, but at no others. This figure will show that if we make them coincide at extreme temperatures the curve falls below the straight line at the intermediate temperatures, or the inertia is too little for the force, and the watch will gain; whereas if we adjust it for any two adjacent temperatures it will lose for all above or below them.

128. Several contrivances have been adopted to effect this object of making the weights move faster when they are nearer the centre. It will be sufficient to describe one of them in such a way as to show the principle of their construction, which is, if compound bars are used, to give them such a curvature as will carry the weights at the ends in a direction more nearly coinciding with a radius of the wheel when they are nearer the centre than when farther from it. It will be easily seen from this drawing that if the curved pieces are made of brass and steel, with the brass inside the curves, they will carry the weights inward as the temperature increases, and that the motion will be more in a radial direction when they are comparatively near the centre than when far from it.



129. The method just now described is Mr. Dent's. It appears from a report of the astronomer royal to the Admiralty, in a parliamentary paper lately published, that the same thing was done to a certain extent and the principle of it suggested by a Mr. Eiffe; and that it has lately been done with great success by Mr. Loseby (several

of whose chronometers have been accordingly purchased for the Admiralty) by means of mercurial tubes, curved so that the expansion carries the mercury outwards, when its extremity is near the centre, more rapidly than it does when the mercury has reached a part of the tube more distant and more curved towards the centre. I have no means of giving a correct drawing of Mr. Loseby's compensation tubes, but the principle of their operation is sufficiently evident.

END OF CHAPTER II.

CHAPTER III.

ON CHURCH OR TURRET CLOCKS.

THE principal difference between church or turret clocks and house clocks is in their size. But this difference makes it necessary to attend to some things in their construction which hardly require consideration in small clocks. Moreover they cannot always be made in the same way, because they have to adapt themselves to various situations, and have very different amounts of work to perform, and are required to satisfy very different conditions as to accuracy and price.

PENDULUM.

130. In all cases, however, the first thing to attend to is the steadiness of the suspension of the pendulum; which may vary in weight from 1 to 3 or 4 cwt., according to the size and number of dials that the clock has to work. No rule can be laid down upon that point; but for the reasons stated in § 39 the pendulum ought always to be as long and heavy as it conveniently can be, and the greater the amount of friction, and therefore variation in force, the train is liable to, from large dials, the greater necessity there is for a powerful pendulum. And the heavier and longer

the pendulum is, the more it will require a firm support; and this is generally best obtained by fixing the cock which carries it to the wall behind the clock. The cock should be cast on a large iron plate, which is fixed by bolts leaded into the wall. The bolts should have shoulders to receive the plate, or else screwing the nuts on will tend to draw them out of the wall. And the bolt holes in the plate should be large enough to allow some motion for adjustment. For cheap clocks the cock may be merely a strong piece of cast iron, leaded into the wall, with a proper opening in it wide enough to carry the spring and *chops* in the manner described for astronomical clocks (26), which is the only way of fixing the top of the spring firmly. But care should be taken to put the cock in so that the pin through the chops will lie quite level and also parallel to the wall, or at right angles to the pallet arbor, and only so much above it that the bend of the spring will come just opposite the end of the arbor.

131. The spring should be broad and thin, not narrow and stiff, and not more than 4 or 5 inches long, from the chops to the pendulum top.* Sometimes, to prevent the pendulum from twisting, two narrow springs are used, separated by about an inch. But a single one, broader than the two together is better, not only because it will affect the vibrations less by its own elasticity, but because, if the two springs are not exactly of the same length

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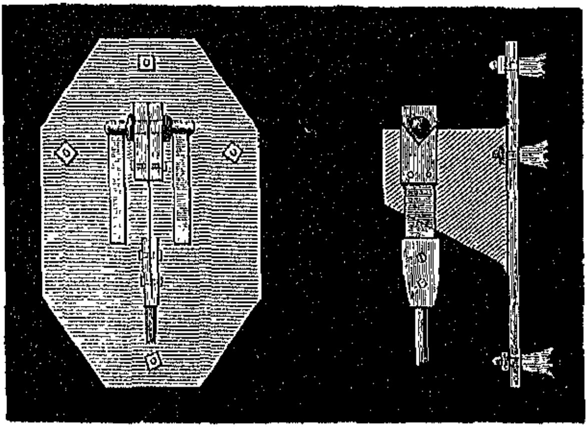
* Mr. Dent has found he can get from the saw-makers better pieces of steel for turret-clock springs than from professed spring-makers, and at half the cost. I have seen some specimens of each, and there is no question which is the best.

and strength, they will tend to twist the pendulum at every vibration. The chops may be as well of cast iron as of brass, and they should be screwed together through the spring as near the bottom as can be. In this drawing I have shown the chops and spring and a side view of the cock and the plate belonging to it, and the *lewises* of the bolts. I have also given a front view of the form of plate which appears to me the best for obtaining steadiness with four bolts.



132. Of course a compensated pendulum is better than an uncompensated one; but the expense of compensating a 14 feet pendulum is an obstacle to their use. The Exchange clock is the only one in England, if not in the world, with a compensated pendulum of that length. Mr. Dent, however, has lately begun to use 8 feet pendulums compensated, with bobs of nearly 2 cwt; and it appears that such pendulums do not cost above £7 or £8 more than

a wooden one equally well made. It may be as well to remark that *cast* tubes of zinc are not found sufficiently solid to expand and contract as they ought to do; and consequently it is necessary to make the compensation tubes of several tubes of the common sheet zinc soldered together, in order to obtain sufficient strength to carry a heavy bob without bending.

133. If the pendulum is made of wood, whether deal or mahogany, it should be as straight in the grain as possible, and free from knots, and not above half an inch thick and two inches wide (which is strong enough to bear several tons); for the thinner it is, the less the weight of the rod, and therefore the radius of oscillation of the pendulum, can be effected by its absorbing moisture, and the straighter the bob will keep it if it has any tendency to bend. It should be dry and well varnished several times over, and the ends ought to be well saturated and all the screw holes, to keep out the damp. The wood should reach as near both to the top and the bottom of the pendulum as the necessary metal terminations will allow; and with that view, perhaps, it is better to make the crutch with a pin to go into the pendulum rod than with a fork: the pin should be adjustable for beat in the end of the crutch. The pendulum should end in a point, and should have a degree plate under it marked to about 10′. It may be convenient to state that the length for a degree on the plate is very nearly $\frac{1}{58}$th of the whole length of the pendulum, and no very great accuracy is necessary, as you only want to see how much the arc *varies*.

When an eight feet pendulum is used, it is generally better to elevate the clock, so that the pendulum is wholly within the chamber, than to let it hang down in a box below; for otherwise the bob cannot in most cases be easily got at to regulate the pendulum, or to observe the arc it is swinging, which affords an indication whether the clock wants cleaning or not. There can be a moveable pair of steps or platform to wind up by, which when not used will go under the clock, and so take up no room, as a fixed platform would. I may add, that the screw for raising the bob ought always to be at the bottom of the rod, and not at the top, or, still worse, at the side of the bob. In a compensated pendulum it would, as a matter of course, be put at the bottom; and in a wooden one it cannot be put at the top without making part of the rod of metal; and if it is put, as it sometimes is, at the side of the rod, a little way above the bob, altering the screw has a tendency to bend the rod, so that the bob does not hang vertically upon it. Care must be taken in making compensated pendulums, both that the bob and compensation tubes do not turn with the nut, and also that when you hold the bob steady, turning the screw does not turn the rod, and so twist the spring; and therefore the zinc tube must not rest on the nut, but on a collar, which slides on a square or some other uncircular portion of the rod, and the collar and the nut should present convex surfaces to each other, to allow the nut to turn more easily. Respecting the shape of the bob, and the method of adjusting, I have already spoken in § 70, 71.

134. There is a practice, not uncommon with country clockmakers, of hanging the pendulum to the wall at the side of the clock instead of behind it, and connecting it

with the crutch (which sometimes goes up instead of down) by a horizontal rod two or three feet long. This, though a convenient arrangement in appearance, is a very bad one for the performance of the clock; for it is evident that the friction, and the shake, of the two additional pivots must tend to diminish the vibrations of the pendulum, or in other words must require a greater force on the pallets to maintain the proper vibration; and therefore, by virtue of what is stated in § 36, must make the clock go worse than if the pendulum were suspended in the common way, just opposite the pallet arbor. No doubt there may be cases in which it is hardly possible to suspend a long pendulum in any other way; and when it is necessary so to suspend it, the horizontal connecting rod should be as light as possible, and its pivots small and accurately fitted to the crutch and the pendulum, so as to diminish the friction and the shake in the pivots as much as possible. Moreover, care must be taken that the crutch and the pendulum move exactly in the same plane, or the impulse of the pallets will tend to make the pendulum revolve in a sort of elliptical cone, instead of vibrating in a plane.

135. If the pendulum cannot be fixed to the wall, or if the clock frame itself is very strong and firmly fixed, it may be hung from a flat iron bar going over the top of the frame, and having a nick in the end broad enough to admit the chops. This bar will have to be screwed into both the back and front of the frame, and before the screw holes are made, it should be carefully adjusted, so that the pendulum will swing exactly in a plane at right angles to the pallet-arbor, and having the edge of the spring exactly opposite

to the end of the pallet-arbor; which may be effected by taking out the arbor, and looking through the two holes in the frame at the spring, and seeing that it is in the middle and appears merely as a line.

FRAME.

136. It is of nearly equal importance that the frame which carries the wheels should be strong and steady. The frame of astronomical and house clocks consists merely of two plates of brass joined together by pillars at the corners. The frames of turret clocks are made of iron bars so placed as to carry the arbors of the wheels. The old fashioned way is to make the frame consist of a front and a back set of bars joined by pillars like a house clock, and requiring to be taken to pieces to get the wheels out when they want cleaning. This is still done in second-rate clocks, though it may very easily be avoided. The frame ought to be so made that when once put together and screwed down to its stand, the substantial parts of it should never be taken to pieces again; and this is either done by making the bars which carry the wheels separate pieces, screwed on to the more solid parts of the frame, or, what is better, as regards the smaller wheels, by making the brass *bushes* which contain the pivot holes to take out, and then the wheels can be removed separately, at any rate sufficiently to clean them. These loose bushes should have their three screws set so as to form an isosceles, not an equilateral triangle; for if they are at equal distances the bushes get put in in different positions, and as the pivot hole is not likely to be be exactly in the middle of all the screw holes, it gets dis-

torted from its true place. If there are only two screws there should also be one steady pin, for the same purpose. The whole of the frame, or of each side of it, should be cast in one piece, and the pillars should have broad shoulders and strong threads and nuts to unite the two sides together, and the frame should be from $\frac{1}{2}$ to $\frac{7}{8}$th inch thick according to the size of the clock. Then the two barrels may be set in separate bars bolted to each side of the frame. All the rest of the wheels may be inserted by means of moveable bushes and without any extra bars to the frame. In this way the frame is stronger, as well as cheaper to make, than if it is made in many pieces which have to be fitted to each other. But there are several varieties of clock frames which it may be as well to describe separately.

137. First suppose there are to be four wheels in the train, as in a house clock, and all the arbors of the same length as the barrel, this being the most ordinary kind of construction. Then a frame such as this will be perhaps the best and most compact form. I have inserted the end of the bar which carries the pendulum, in order to show how it is to be placed if the pendulum is not fixed to the wall. I have not indeed seen a frame of this form, and possibly the arrangement may be found on trial to require some little modification; but a clockmaker to whom I suggested it said he should use it; and when it is necessary to resort to a four-wheeled train, this kind of frame will carry the wheels with a less amount of iron work than usual. P P P P are the four pillars, and a fifth might be inserted in a large clock in the cross bar which carries the scapewheel and the hammer lever, and which has the locking

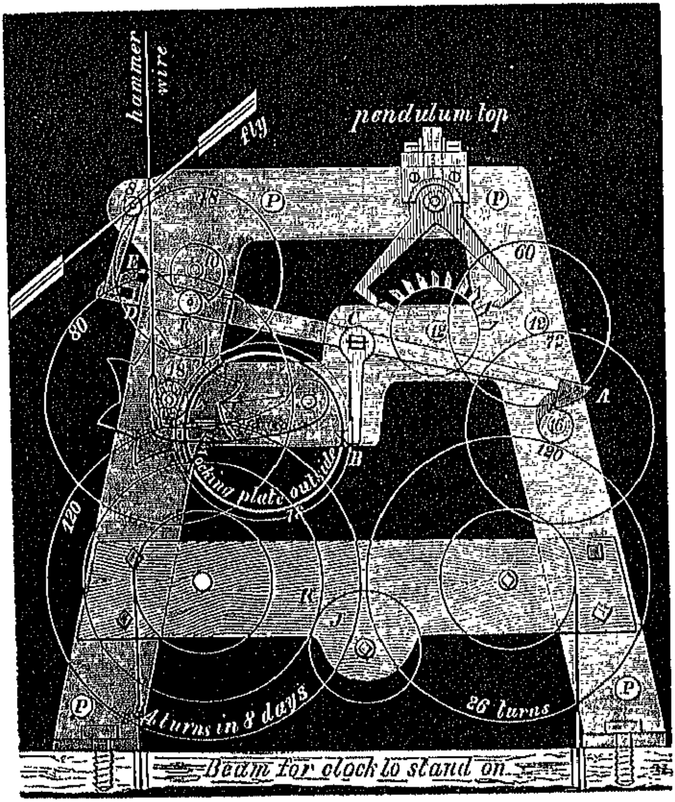


plate set upon a stud outside. The numbers of the teeth which I have inserted are of course arbitrary, and may be altered in the proper proportions.

I have put down the great wheel of the going part as turning twice more in the week than the striking great wheel, because the striking part almost always requires a heavier weight, and therefore a thicker rope than the going part. The requisite thickness of rope can be altered by altering the diameter of the barrel or the fall of the weight; or if the fall is limited by the situation the weight can be increased and an additional pulley added. It is, however, to be remembered that every extra pulley adds very considerably to the friction and requires a still further addition to the weight to overcome that friction. I was lately able to take 40lbs. off a striking weight by merely removing a guiding pulley which had been needlessly introduced. It is a matter of experiment what thickness of rope a given weight hanging by a single moveable pulley requires: a good rope half an inch thick appears to be strong enough for any weight that is ever put to such a clock; and consequently the barrels need never be more than a foot long in a clock of this sort, as it is not supposed to be one of very large size.

138. If the striking wheel has eight pins, it must have eight times as many teeth as there are leaves in the pinion of the wheel above it, in order that that wheel (which I called before the second wheel) may turn once for every blow that is struck (see § 93); and the second wheel must also drive the fly some exact number of times in each revolution of its own, since in turret clocks the fly arbor is made to carry the pin which is stopped by the detent D when they have done striking, as before described, the fly itself being set outside the frame and having arms a foot and a half long or more to carry the fans, and therefore moving much more slowly than in house clocks, where it is within the frame. These arms are not rigidly fixed to the arbor but to a socket which turns upon the arbor, and has

a ratchett and click so placed that when the arbor is driven by the clock it carries the fly with it, but when the clock is stopped at the end of the striking the fly can go on by its own momentum, as it could not be stopped suddenly without the risk of breaking something. It is this motion of the fly over the ratchett-teeth which makes the noise like winding up that may be heard in the tower after a church clock has done striking.

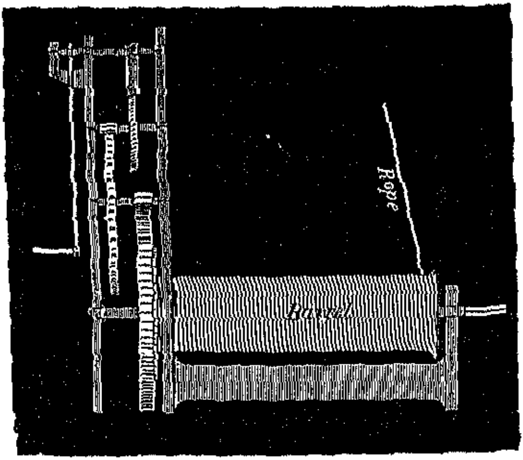
In the above drawing the locking-plate or count-wheel B L is outside the frame, and is driven by a small pinion of 8 set on to the projecting arbor of the striking-wheel. The lifting piece A C D is set on an arbor which is within the frame but projects through it and has the arm C B set on to it outside, which works into the locking plate. At F there is a roller which rolls upon the circular plate with a piece cut out of it fixed to the second wheel. The snail at A on the centre wheel raises that end of the lever, and therefore depresses the other end, so that the pin in the fly-stop slips past D and rests against E when the clock 'gives warning.' When the snail lets the end A of the lever drop, the fly is set at liberty; and as the second wheel begins to move, the circular plate and roller depress the lever so far as to let the fly-pin clear both the stops D and E, and then the locking plate by means of the arm C B not only keeps the lever there but moves it a little farther in the same direction, merely for the purpose of taking the friction off the second wheel which moves quickly, and transfering it to the locking-plate which moves very slowly. In fact the roller F is not strictly necessary, for the locking plate alone might be employed to raise the lever, as described in § 93; but it is safer to have it raised at first by a wheel that moves so quickly that the lifting-piece is sure to be out of the way before the fly has made one revolution. Of course the end A of the lever must be made a little heavier than the other end.

THREE-WHEELED TRAINS.

139. I have supposed each train to have four wheels. But it is evident that it will move with less friction if the teeth can be so proportioned that there may be only three wheels. Now if we assume that the centre wheel shall turn once in the hour, we can hardly make the scape wheel, which is now to be the next to the centre wheel, turn in less than four minutes, which however can be done where there is a two seconds pendulum with a scape wheel having sixty pins instead of teeth in it; but it requires a large number of teeth in the centre wheel. In this case the great wheel may remain the same as before. In the striking train the second wheel is dispensed with, but a longer fly is required; and if the number of pins in the striking wheel remains the same the great wheel will also remain unaltered. The locking-lever however will have to be altogether worked by the locking-plate, which requires very accurate adjustment of the nicks to make the lever rise and fall exactly at the right time, and the locking-plate must be large in proportion to the length of the arm C B in order to raise it quickly enough. Altogether this is rather a critical movement, though I have seen it answer very well in well made clocks, such as Mr. Vulliamy's, who generally uses it, as well as the corresponding going train.

140. But there is another way of making three-wheeled trains, which is better on several accounts. First of the going train: it is not at all necessary that the centre wheel should go round in an hour; for there may be a subsidiary wheel (*i. e.* a side wheel not forming part of the train), which turns in the hour, and drives the dial-work; such a wheel is in fact used in the three-wheeled train I have just now described, to reverse the motion; and an extra wheel of this sort does not cause nearly so much friction as the introduction of another wheel and pinion into the train. Suppose we make the great wheel to turn in three hours instead of six or eight, as in the four-wheeled train; then, if it has 120 teeth, and the next pinion 12 pins or leaves, the second wheel will turn in 18 minutes, and if that has 108 teeth, and the scape-wheel pinion 12 as before, the same pendulum and a scape-wheel with 30 pins only, or an eight feet pendulum with 40, will do. This is the train in Mr. Dent's large turret clocks, with occasional variations of the numbers for particular purposes.

The subsidiary wheel, to be worked by the great wheel, must be one-third of its size, so as to turn in the hour: the manner of fixing this wheel I shall treat of under 'adjusting work.' But if the barrel turns in three hours instead of eight, it will have to make 64 turns in the eight days instead of 24, and so will require a much greater length, and if all the arbors are made of the same length as this long barrel, it will make the whole machinery very heavy. In order to get rid of this objection, what is called a double frame is generally resorted to; that is, the barrels and their great wheels have their back arbors in the same frame as the rest of the wheels, but the front or winding up arbors in a separate frame standing some distance in front of the frame that carries the other wheels. By this arrangement the arbors of the other wheels can be made lighter even than in a clock with a short barrel.



There is another advantage in this as regards the striking part, viz., that when the great wheel turns so often as once in three or even four hours, the striking pins can be put on the great wheel itself, as it is large enough to carry the 26 pins required for one-third of the twelve hours. The exact number is indeed immaterial, except that the more pins it has the fewer coils of rope it will have to carry for the eight days. Now it is evident that the striking will be done with less waste of power when the power has not to be transmitted through the pinion of a second wheel, in which it loses considerably by friction: I shall have to state afterwards the surprising extent to which this loss of power takes place. The wheel next to the great wheel can then be made to raise the locking lever in the same way as the second wheel does in the four-wheeled train. The more turns the rope takes over the barrel the easier also it is to wind up, and the difference in moderate sized clocks may be such as to save the necessity of having what is called a *jack* to wind up with, which is generally required for the striking part of clocks with short barrels, except with small bells.

141. This apparatus may be either fixed or moveable. If it is fixed, as it ought to be when required at all, the end of the barrel opposite to the great wheel is made into a toothed wheel K (in the drawing of the four wheeled train), and by the side of it is put a smaller wheel or pinion J which works into it; and instead of the winding square being made on the arbor of the barrel, it is made on the arbor of this pinion, which of course gives greater power in winding the clock up, by requiring more turns of the key or winch to do it. The pinion is sometimes made to push backward and out of gear with the wheel when the clock is not being wound up. The loose jack consists of a frame containing a wheel and pinion with the arbor of the pinion squared to form the winding square: the arbor of the wheel is a socket with a square hole in it which fits on to the barrel arbor; so that when the jack is applied and made to rest on some part of the clock frame, it becomes (except that it requires a thicker arbor as will be explained presently) just the same as if the wheel had been set on the barrel itself, and the pinion in the clock-frame.

The going part never requires a jack wheel to wind it up except in very large clocks: but I am not sure that it would not be better to apply such a wheel (I mean of course a fixed one) more frequently, even where the weight is not too great for a man to wind up without it; because the effect of having to wind up on the barrel arbor is that it must be thick enough to carry a winding square strong enough not to twist, and therefore that pivot requires to be a good deal larger, and therefore has more friction, than would be necessary if it had merely to carry the weight. The two cast iron wheels that require to be added for winding by a jack wheel cost very little, and the plan also saves something in the construction of the barrel arbor and great wheel. By a little contrivance one winding pinion might be made to apply to all the three barrel wheels: indeed there is no reason why the winder itself should not have that pinion, instead of a pipe, set on an arbor, fitting into proper holes to wind up all the barrels by.

142. Long barrels however cannot always be properly used; because if the rope does not hang down, but is carried over a fixed pulley above or at the side of the clock, and there is not a considerable distance from the barrel to the fixed pulley, the rope will not run straight enough off the barrel towards the end, but obliquely as shown in the last drawing, and consequently, instead of travelling along the barrel as the clock is wound up, it will turn back again and overlap itself; and even if it does wind up without overlapping, there will be so much rubbing between the successive coils of the rope as will soon wear it out, and will moreover render a heavier weight necessary. In all

cases where a fixed pulley is required, it ought to be as far as it can be placed from the clock, in order to diminish the obliquity of the rope as much as possible; I should say that the distance ought not to be less than eight times the length of the barrel.

Sometimes in order to avoid long barrels the rope is made to go twice over them; but this is a most abominable practice; for the weight has of course more power when the rope is coiled the second time over the barrel, as that is the same thing as making the radius of the barrel larger by the thickness of the rope, and so the force upon the clock is not uniform; and secondly, it wears out the rope more than anything else that can be done to it. When the position of the clock is such that the fixed pulleys cannot be as far off as about eight times the length of the barrels, the clockmaker should not be allowed to use long barrels.

143. There are however two ways by which the advantages of the long barrels may be obtained without their disadvantages. The first is by using wire ropes instead of hemp;* but great care must be taken that they are good, as there are some very bad ones made; and they should be tried for some time beforehand with a heavier weight than they will have to bear, and above all by winding them up frequently, or they will cause constant trouble and expense after the clock is put up. In this way very elegant clocks can be

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* In the Windsor Castle clock Mr. Vulliamy used catgut ropes (wire ropes were not then invented); but they are enormously expensive: he was told that 17,000 *sheep* contributed their entrails to compose these catgut lines.

made, with great strength in a small compass, and with only three wheels in each train, and striking from the great wheel. A picture of one is given in the frontispiece.

144. The second method is to put about twenty striking pins on one side of the great wheel and another set half way between them on the other side, and make them raise two hammers alternately: forty, or even thirty, are too many for one side of any but a very large wheel made in a particular way, which will be described presently. Mr. Dent, until he lately at my suggestion adopted this other method, constantly used the two hammer plan; and it answers very well; and such clocks strike with much less waste of power, even when made in cast iron, than the most highly finished clocks with polished steel pins set on the second wheel. A wheel of this sort with forty pins will turn very nearly twice in the twelve hours, or thirty-one times in the eight days, for which a barrel of moderate length will be sufficient, especially as a smaller weight and therefore a thinner rope will do the work than in a train striking from the second wheel.

145. Or again, cheap clocks with short barrels might be made with about twenty pins on the great wheel and one hammer, to wind up twice a-week: a condition to which a good many clocks are practically reduced which pretend to be eight-day clocks, from being so placed that they will not go full seven days. And those who can only afford to spend a small sum upon a church clock had much better have a good one made in this way than a bad one to go eight days.

In every clock the going part ought to go half a day longer than the striking part, in order that, if it is forgotten, the clock may proclaim by its silence that it wants winding up before any harm is done.

Lastly, the reader may be reminded that in calculating the teeth and pinions required for driving the hour wheel by the great wheel separately from the train, the number of the teeth of the great wheel is immaterial; for in that case the hour wheel will evidently turn in the same time as if it were put in the place of the great wheel. Suppose the scape wheel turns in m minutes and its pinion has p_1 leaves, and let t_1 be the number of teeth of the wheel that drives it, whose pinion has p_2 leaves, and let t_3 be the number of teeth of the hour wheel: then $\frac{t_1\, t_3}{p_1\, p_2}$ must $= \frac{60}{m}$.

Suppose $p_1 = 8$ and $p_2 = 10$ (which will be enough if they are lantern pinions, though not otherwise) and $m = 2$; then if $t_3 = 24$, t_1 must $= 100$, and the second wheel will turn in 25 minutes; and if t_2, the number of teeth of the great wheel, $= 144$, it will turn in six hours, or will require only thirty-two coils of rope for eight days. In this case the hour wheel had better be made as a large lantern pinion. And if the great striking wheel has twenty pins or cams on each side raising two hammers alternately, as above mentioned, an eight-day clock may thus be made with only three wheels in each train, with moderate numbers for the teeth, and without requiring the scape wheel to turn so slowly as in four minutes, and without resorting either to long barrels or wire ropes.

146. When the great wheel is the striking wheel, the second wheel must turn exactly one-half or one-third round for every stroke, and the circular plate before described in

the four wheeled train must have two or three pieces instead of one cut out accordingly, to let the roller on the locking lever fall at the proper time. Moreover this wheel will turn too quickly for it to work the locking-plate by a wheel and pinion, as it would require at least 234 teeth on the locking-plate wheel. If the clock is wound up by a jack wheel as before described, the barrel will ride upon the arbor of the great wheel, and that arbor may carry a pinion or small wheel to drive the locking-plate, just as the striking wheel of the four wheeled train did. But when the weight is small enough to be wound up without a jack, the arbor must belong to the barrel and not to the wheel, and therefore cannot drive the locking-plate. In that case it must be done in one of the following ways.

The most simple method is to set the pinion on the great wheel itself: and in every case the wheel or pinion that drives the locking-plate, if it is set on the striking wheel, must have as many teeth as there are striking pins, assuming the locking-plate to have 78, or in the same proportion. 2. Although the second wheel turns too quickly to drive the locking-plate by a toothed wheel and pinion, yet it may do so by means of a ratchett-wheel on the locking-plate and two gathering pallets, (like the common repeating movement, § 90) set on the arbor of the second wheel: the locking-plate must also have a click set over the ratchett to keep it in its place when the pallets are not acting. A third way is to make the barrel arbor hollow nearly up to the end which forms the winding square, and make the arbor of the great wheel go into it; so that the barrel arbor comes through the front frame, but the wheel arbor goes the back frame and carries the pinion that drives the locking-plate. This, when it is well done, is a remarkably neat arrangement, but it requires very good machinery to bore the hole truly all down the barrel arbor, and if it is not done truly it had better not be done at all, as it is sure to stick fast. These short trained clocks may of course be put in a frame of the same kind as the four wheeled one of which I gave a drawing. But they afford facilities for a more convenient arrangement, by setting the going and striking parts, or at least the upper wheels of them, in separate small frames, which screw on to a large and strong horizontal frame cast all in one piece, which may carry the great wheel of the striking part, and indeed of the going part also.

The clock in the frontispiece is an example of this kind of frame. The great striking wheel is carried by a large cast iron cock on each side, bolted to the main horizontal frame, the surfaces in contact being planed so as to fit accurately. The second wheel and the fly arbor are carried by a small triangular frame at each end, which screws on to the main frame. The locking-plate turns on a pin or stud set on the frame, and as there is a jack wheel to wind up by, the great wheel arbor comes through the front cock and drives the locking-plate. The great wheel of the going part being lighter and smaller than the striking wheel is carried in the same triangular frame as the rest of the going wheels; but the scape-wheel and the bushes of the second wheel are made to take out without removing the great wheel or taking the frame to pieces. It is not of much consequence whether the second wheel can be got completely out, or not, for if the bushes are removed it can be cleaned within the frame as well as if it was taken out. The scape-wheel however, and the pallet arbor, should be made to take out completely, without undoing the frame; and for this purpose nothing is required but the bushes to be fixed with screws instead of rivetted in, as there is always room enough for the scape wheel to pass the second wheel.

147. I proceed to point out some other things which require to be attended to in turret clocks, in addition to those relating to clocks in general, mentioned in the first chapter.

ESCAPEMENT.

The scape-wheel and its arbor, as before observed, should be as light as it can be made of proper strength; remembering also that the fewer pins or teeth it has the lighter it should be made, as it has to move farther at each beat. The pivot of the pallet arbor ought to come close up to the pendulum spring; for if it does not, the force is communicated to the pendulum with a tendency to twist the crutch: no such effect will of course be visible, but the tendency to it produces an unnecessary friction on the pivot, and requires greater thickness and therefore weight in the crutch to resist it. In the Meanwood clock the crutch is entirely outside the frame, straight, thin, and broad, and therefore as light as possible, the pivot being set in a cock like that of a common house clock. Sometimes however the frame is so made that the pallets and crutch could not be taken out if they were set in this way;

and in that case the pivot should be set in a bush projecting as far as the pendulum spring, the crutch having a bend, and springing from within the frame in the usual way. It is to be remembered that the crutch is itself a pendulum of which all the weight is carried by the pivot holes, and a heavy crutch and arbor produces considerable friction, which, like all other friction, is variable, and moreover consumes force, diminishing the arc of the pendulum like the dead friction on the pallets, of which the effect has been already explained.

For the same reason the pivots ought to be as small as they can safely be made, and also with as little shake as will let them move freely; and the crutch should be long that little may be lost by the necessary shake of the pendulum in the fork. Whether the crutch ends in a fork embracing the pendulum rod or a pin going into a hole in it, it should be made with some screw adjustment to put the clock *in beat.* And in trying whether a clock is in beat the pendulum should be allowed to move only just far enough to let it escape, and then the smallest deviation will be easily observed. It may be a convenient rule for unprofessional clockmakers to remember, that in all cases if the right hand beat (*i.e.* the beat heard when the pendulum is at the right) comes too soon after the left hand one, the fork wants moving to the right with reference to the crutch, and *vice versâ.*

148. A very neat contrivance has lately been introduced by Mr. Dent into his turret clocks. It occasionally happens that if the pendulum is moved while the scape-wheel is standing still without any force upon it, the end of one of

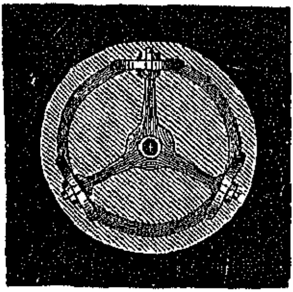
the pallets just catches the point of a tooth so that it cannot slide up the pallet, and the momentum of a heavy pendulum is then certain to break the tooth. In order to prevent this the two sides or prongs of the fork are set upon springs, which tend to bring them together and keep them close to the pendulum rod, with a stop of the proper thickness between them. The springs are strong enough to give the impulse to the pendulum, but if one of the pallets should be stopped, the spring on the opposite side of the fork gives way and lets the pendulum go on. The reader may fancy that a single spring in the crutch would do as well; but it would not; for a single spring would not have sufficient resistance *both ways* to communicate the impulse to the pendulum without bending; therefore there must be two springs, both in a state of tension in opposite directions. The little frame that carries the springs screws on to the crutch in the same way as a common adjustable fork.

DIAL WORK.

149. In turret clocks the dials and dial work are generally at some distance from the clock. The dial work consists of an arbor which carries the long hand with a wheel upon it, and upon this arbor is the short hand socket with its wheel, and the two work together in the way before described in house clocks. These wheels are all set in a small separate frame fixed behind the dial, and all the wheels and arbors should be made of brass, as it is generally not very easy to get at the dial work to oil it; and so if made of steel the pinions are liable to rust. The

hour arbor projects through the front of this frame, with a half universal joint, and if it is on the same level as the clock, it is merely connected with the hour wheel of the clock by a straight rod. If the dial work is above the clock it must be connected by bevelled wheels, one pair at the clock and the other pair at the dial work, or, if there are more dials than one, at some convenient point where the rods converge from the dial work of each dial, according to the position of the clock. These vertical and horizontal *leading-off* rods are sometimes made of tubing, either iron or brass, as it is stronger than a solid rod of the same weight and strong enough to resist bending by its own weight as well as twisting. In the same way I may mention that small iron gas-pipes with solid pivots fixed into their ends are sometimes used when cranks with long arbors are required for connecting the hammer with the wire coming up from the clock. But where the vertical rod is required to be long and consequently heavy, it is generally better to make a wheel at the top of it rest on friction rollers, and then the weight of the rod has no tendency to bend it, and it only requires to be strong enough not to twist, for which a half inch iron rod is sufficient in almost any case. These friction rollers may be made in various ways; on the whole the best way appears to be the following, which will be readily understood from the drawing over the page.

The rod has a circular plate fixed to its top, and there is a similar plate fixed to the beam through which the rod passes. These plates are not quite flat, but they each have a broad circular groove in them near their edge and the



grooves exactly face each other. Now if three or four equal balls or cheese-shaped rollers were laid on the groove in the lower plate, and the upper plate let down upon them, it would turn with no friction except that of the *rolling* of the balls, which would always keep their original distance. The revolving roof of the building which contains the great telescope at Cambridge turns upon cannon balls in this way; and the balls running in the grooves cause it always to turn on the same imaginary axis without the necessity of a real one. However on this small scale, in order to prevent the balls from slipping and so getting all together, they are set upon a three legged axis with a hole in the middle which surrounds the rod; but it has nothing to do as an axis: that is, it carries no weight and has no contact with the rod, and has merely to prevent any of the balls from not rolling on in case the upper plate should for a moment be lifted off that ball. Consequently the friction (so far as regards the weight of the rod work) is true rolling friction, which is much less than the friction of *friction wheels* of any moderate size carrying the weight upon their axes. I understand that rollers of this kind have been applied to large weather-cocks with long rods to work a dial within a building, and tried with heavy additional weights without producing any material difference in their freedom of action. It should be observed that the cross section of the rollers must be of higher curvature than that of the grooves, so that they may only have contact at one point, and not rub as well as roll: complete surface contact without rubbing could only be obtained by conical rollers between conical plates, the points of all the cones converging in the centre of the rod; but such rollers would have a tendency to slip outwards, and would require greater accuracy in making than these 'cheese shaped' rollers.

The long vertical rod is connected with the arbor of the bevelled wheel in the clock by means of a half universal joint; and in fixing it in cold weather it should be remembered that an iron rod thirty feet long will become $\frac{1}{10}$th of an inch longer with 40° of additional heat, and brass tubes about half as much more; and play enough must be left in the joint accordingly.

Where the clock does not stand in the middle of the chamber, under the point of convergence of the dial rods, but near the wall, an additional pair of bevelled wheels is required. This might be avoided by making bevelled wheels of a different angle from 45°, so as to lead directly to the two side dials from the place where the vertical rod comes up; but nothing material either in expense or friction would be saved thereby. The bevelled wheels, especially those which have to work several others, ought to be large and strong; and when, as sometimes happens, their diameter is limited by want of room in the clock, it ought to be made up in thickness, which however gives more friction than larger wheels with more teeth.

ADJUSTING WORK.

The adjusting work, for setting the hands when the clock wants altering, is sometimes very defective. I have seen a clock in a cathedral put up only a few years ago, as I was told, by a London firm of large business, in which the only means of putting the clock forward is by taking out the bush of one of the wheels (which is furnished with hand-screws for the purpose) and shifting the place of the pinion upon the teeth of the next wheel. I should think the man who has the charge of such a clock takes very good care always to keep it on the gaining side, as he can stop it for a few minutes every now and then with infinitely less trouble than he can put it forward in this barbarous fashion. The adjustment is generally made merely by a friction spring as in a house-clock (73). And where there is only one small dial this method is safe enough; but otherwise the spring must either be so strong that the hands cannot be altered without applying great force to the wheels, or else they will be liable to slip for want of sufficient friction or pressure of the spring. In large clocks therefore a better way of making the adjustment is by what may be called a square ratchett, *i.e.* one which wants the click lifting by hand to enable it to pass either way, each division corresponding exactly to one or two minutes; or by clamping screws.

When there is no hour wheel in the train this ratchett is sometimes set on the great wheel arbor, turning in three hours suppose, and with a large bevelled wheel attached to it, which drives the first leading off bevelled wheel, of one third its size and number of teeth. This has one advantage, viz: that the friction of a subsidiary hour-wheel is avoided; which however is much less than if it were an additional wheel and pinion in the train: the large bevelled wheel also carries three pins instead of one, to let off the striking part. But it has several disadvantages: first, the small bevelled wheel is necessarily of small dimensions; since even the large one, which is three times the size, must be made smaller that the great wheel itself, or it could not be got into the frame: secondly, the discharging pins cannot be relied on to let off the striking part correctly within several seconds in this way: thirdly, when the leading off is wanted in any but a vertical direction, the arrangement becomes clumsy and inconvenient; fourthly, the ratchett-wheel, bevelled wheel, and pins add nearly two inches to the length of all the arbors; and fifthly, in some positions of the wheel the adjusting click cannot be got hold of without great difficulty. I think any of the following methods are better, and some of them may be easily adopted in any clock, according to circumstances.

When the hour-wheel is not in the train it is to be a thick wheel of the proper size to be driven by the great wheel according to its velocity. It is not fixed to its arbor, but rides upon it close to a plain or blank wheel, which is fixed to the arbor, as are the discharging snail and the first leading off wheel, if any are required. If the dial is a small one the hour-wheel and the blank-wheel may be connected by a friction spring as usual; otherwise the connection may be made, either by one or two clamping screws, or by a pin which goes through a hole in the hour-wheel and into any one of sixty or thirty holes in the blank wheel, being kept in its place by a spring, and having a projecting handle by which it can be pulled out and the relative position of the two wheels shifted through a space corresponding to one or two minutes. Another way, perhaps still more simple, of making the adjustment by a definite quantity, would be to make the hour-wheel, instead of riding or turning on its arbor, to slide upon it by means of a square, or what is called a *key;* when you want to alter the clock you would only have to slide the hour-wheel out of gear with the great wheel and slide it in again with different teeth in contact, and it might be kept in its place either by a pin or a spiral spring of wire round the arbor. Where the clock has a train remontoire, which may itself require adjusting, as described in § 177, clamping screws must be used; because altering the remontoire by any less quantity than the twenty or thirty seconds at which it lets off would make the hands point wrong, if they could not be altered by as small a quantity as the scape-wheel. Where either of the other methods is adopted, so that the hands cannot be altered by less than a minute, the smaller adjustments must be made by stopping the scape-wheel for the requisite number of seconds; and on this point I shall have to make some further remarks in § 187.

SIZE OF DIALS.

151. The size and strength required for the going part of a clock depends entirely upon the number, size, and situation of the dials; though there seems to be a notion among clockmakers that the going part and the striking part ought to correspond in size, and I have seen a clock without any dials, in which the going train was heavy

enough to work four dials 10 feet wide. They ought to be treated quite distinctly; though of course it will frequently happen that where there are large dials there will be a large bell also. The more turns in the week the great wheel makes, the less strength and size it obviously requires; and in all cases broadness of the teeth, *i.e.* thickness of the wheels, should be looked to rather than depth of the rim, as broad teeth cut the pinions less than narrow ones.

The size of the intended clock dials is a matter which church architects frequently pay no attention to until it is too late, or do not understand. Mr. Vulliamy states in his pamphlet the sizes of several well known public dials in London:

St. Martin's-in-the-Fields - - -	8 ft.
St. James's, Piccadilly - - -	10 ft.
Islington church - - - -	9 ft.
The clock on the Queen's Stables -	6 ft. 10 in.
St. Paul's - - - - - -	17 ft.
Horse Guards - - - - -	7 ft. 5 in.

To which I add from other information:

	DIAMETER.	HEIGHT.
St. Luke's, Chelsea* -	6 ft. 10 in.	72 ft.
Bow Church - - -	9 ft.	70 ft.
Marylebone Church -	7 ft.	about 60 ft.
Royal Exchange - -	9 ft.	90 ft.

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* As a proof of the reliance to be placed on architects in these matters, I have seen a letter from an architect of some reputation, stating as a justification for the dials which he had prepared, and which the clockmaker objected to, that the first two dials in this list, and that of the Horse Guards, were only 5½ feet in diameter: which his employers had of course believed.

And the great clock at Westminster is intended to have dials 23 feet wide, at the height of about 220 feet.

The result evidently is, that unless all the above dials are too large, which anybody may see they are not, dials ought to be so placed that they can be about a foot in width for every ten feet from the ground; though this is not sufficient for heights under 50 feet. Any one who looks at dials of less than this proportion, such as St. Pancras, 6 ft. 6 in. at a height of about 100 ft., or the dial on the church in Chester Square, which is a little more than 4 feet, and at a very moderate height, will see a further proof of the necessity, not only of making the dials large enough according to the above rule, but of placing them where they can be made large enough for their own height, without being too large for the surrounding parts of the building. The consequence of not attending to this is that the tower is defaced, and its 'details' overwhelmed, by what appears at a little distance only a great black spot, too large for the building and too small for the clock. It is hopeless to make a clock face an architectural ornament: at least every attempt that I have seen of that sort in a gothic building has been a most wretched failure, both in architectural beauty and horological distinctness. The best thing that can be done is to put the dials on some plain flat surface large enough for the purpose; and if such a place is not provided at first, it is ten to one that a clock-face will some day be substituted for the tracery of a window (as three *illuminated* dials have been in the heads of the windows of the fine tower of St. Mary's at Beverley), or built round the bottom of the spire, projecting 'like the eyes of a great cod-fish,' as I heard remarked by a spectator of three dials stuck round the spire of a small country church by the architect just now alluded to.

152. The material of the dial may be stone, slate, copper, or iron. If the dial is made of stone it should have the part within the figures, in which the short hand traverses, cut out or countersunk to the depth of an inch and a half, in order that the long hand may lie closer to the figures, for the sake of avoiding *parallax* as much as possible. The effect of parallax is that when the hand is in any position except nearly vertical, the line of vision from the eye of the spectator to the hand of the clock does not fall on the place to which the hand is really pointing, but somewhere above it, depending on the distance of the hand from the face and of the height of the clock above the spectator. The same may be done with slate dials; but they are more expensive to cut than stone. Stone dials should be painted all over, black for gilt hands, or white for black hands, like one of the Horse Guards dials. Slate may also be painted, though it will keep a tolerably dark colour without painting, especially if it be occasionally oiled. For large dials the slate will have to be in two pieces. The figures and minute marks are better cut than merely painted and gilt on the flat surface, as their place is then fixed once for all: otherwise they are not unlikely to be incorrectly divided in subsequent painting. In copper dials this cannot be done, nor the countersinking of the middle of the dial, without great additional expense; and the dial is also obliged to be made convex in order to

preserve its shape: the convexity should however be as little as possible, as it either increases the parallax or requires the long hand to be bent to come nearer the minute marks, which has a bad appearance: an inch in 5 feet seems to be enough convexity.

I am not aware that there is any objection to cast-iron dials, provided they are kept well painted; and they are cheaper than copper. They have also the advantage of requiring no convexity, and the centre can be cast countersunk. I have seen the figures and minute marks made projecting, which however does not look well, and is objectionable, as the hand may be blown against them. They are better countersunk a little, for the reason I gave just now; and I may observe that the countersinking should not be *square*, so as to leave corners in which the wet will lodge, but a curved hollow like the fluting of a pillar. Round dials always look better than square ones with the spandrils filled up with some attempt at decoration: a dial is from its nature necessarily a round thing, and it has no business to pretend to be a square one; even arches set in square heads only belong to the worst style of gothic architecture, and round windows belong to the best style. But dials should not be set deep in the wall, like windows, or the rain will not wash them.

ILLUMINATED DIALS.

153. Illuminated dials are made of an iron frame work or skeleton, in the form of a ring, consisting of the figures and minutes and the three rims which bound them. The

middle of the dial must be one piece of ground plate glass, for any division in it would cast a shadow and be mistaken for the hands. Glass is also put behind or between the figures. Several gas-burners are put behind the dial, and the cocks of the burners are connected by levers with the dial work, so that the clock itself turns the gas nearly off (but not so far as to put it out) when the day dawns, and turns it full on when it becomes dark. This is adapted to the different lengths of the day by pins which are screwed in from time to time by the person who has the care of the clock; though of course by the addition of more complicated machinery the regulation of the 'gas-movement' for the length of the day might be made self-acting.

Another way of illuminating a dial, and a much better one, when the building admits of it, is that which is used for the Horse Guards clock; on which a strong light is thrown from a lamp, with a reflector, placed on the projecting roof in front of the clock tower.

SIZE OF FIGURES.

154. In nearly all public dials the figures are made too large; for the larger they are, the more they contract the really useful part of the dial; it will be seen that in most public dials the figures nearly touch each at their inner circumference; and consequently that part of the long hand which is over the figures cannot be distinguished at all at a moderate distance, and the dial might as well be only two-thirds of its actual size. Nobody wants to *read* the figures; twelve large spots would do just as well,—and

better; for then the long hand could be more clearly seen between them. The figures ought not in any case to be larger than a quarter of the radius of the dial; and they ought to be rather narrow, or their different strokes close together, so as to keep the VII and VIII and the other wide figures visibly apart from each other. It may be as well to inform those who have not seen it tried, that it has a bad effect to make the figures narrower at their inner circumference than at the outer, as if the strokes were formed by radii of the dial; and this is a further reason why the figures should be small. The five-minute marks should be a good deal larger than the other minute marks, or it is not easy to distinguish which minute belongs to the figures that consist of several strokes.

155. Both the hands should be broad; and the short hand only should have a *heart* or a broad part a little way from its point, and the point of it ought to be entirely within the figures, and not half covering them as it sometimes does: the long hand should be straight, plain, and ending in a point, like a straight sword, just half way over the minute marks. These directions may seem needlessly particular; but the object of clock faces is to show the time distinctly as far as possible; and any one who will compare the few in which these things are attended to with the many in which they are not (indeed I hardly know any in which they are all attended to) will see that the attention is not thrown away; and as it costs no more to make the figures and hands in this way than in the common way, there is no excuse for not doing it, unless some other way really better can be found. The material of the

hands is almost always copper, gilt, and stiffened at the back for some distance with a rib of brass. Iron would be lighter for the same strength, and when zinced or 'galvanized' before gilding there appears to be no reason why it should not answer as well as copper: indeed it is proposed to make the hands for the great Westminster clock in this way.

156. There is some difference of opinion whether the hands should be counterpoised externally or internally; for one or the other they must be on account of their great weight. If they are counterpoised internally, the force of the wind is not counterpoised at all, and it tends to bend the hand and drive it against the dial, or, if the hand is strong enough to resist that, to bend the arbor which carries it; whereas if it is counterpoised outside, the pressure of the wind against one arm of the lever is balanced by that against the other, and there is no lateral pressure on the arbor. And in like manner when the wind tends to *turn* the hand in one direction it will tend to turn the counterpoise in the other direction, and so there will be no strain on the teeth of the wheels, which in large dials, with the leading off or dial wheels not strong enough, has been known to break them. The objection to an external counterpoise for the long hand is that if it is gilt it will be mistaken for one of the hands, and if it is black like the face it will partially hide the hour-hand for about two minutes in every hour. My own opinion is, though it is contrary to the modern practice (which has perhaps been adopted by clockmakers to guard against the propensity of painters and gilders to gild the counterpoise), that the

partial hiding of the short-hand for a minute or two is of far less consequence than the pressure upon the arbors and upon the train of the clock, which is caused by the want of an external counterpoise, whenever there is a high wind; and I should accordingly (especially where the dial is high and large) have a black external counterpoise to the long hand, with its broad part (which it requires to make up for the want of length) falling just within the inner rim of the figures, and therefore just beyond the heart of the short-hand. The black counterpoise of the short-hand will of course cover nothing but the black face. There ought however to be set on each of the dial rods inside, a longish arm in the same way as an internal counterpoise, to enable a person fixing the dial work to know the position of the hands outside. It is not uncommon to see three or four dials on a tower all showing different time, or to hear the clock strike when the minute-hand is not pointing to the 60th minute. When internal counterpoises are used, the arms which carry them should be as long as the space will allow, because the shorter the arm is which carries the weight the heavier the weight must be, and the greater the constant pressure on the arbors and sockets.

MAINTAINING POWER FOR WINDING UP.

157. As turret clocks take longer time to wind up than house clocks, they still more require some maintaining power to keep them going during that time. In the best clocks Harrison's going ratchett (72) is used; but care must be taken that the spring has play enough to keep the

train going with proper force the whole time of winding. In clocks of moderate size the spring may very conveniently be made merely of steel wire, wrapped in coils with about ⅛th of an inch interval between them, round a rod bent into in a circular arc, of which one end is fixed to a spoke of the great wheel and the other end runs through a socket screwed to a spoke of the ratchett wheel, so that the spiral spring is compressed between the two, being kept in its place by the circular rod run through it. In very large clocks however it is difficult to get force enough with springs of this kind, and therefore they must be of the shape drawn in § 72; and in all cases there should be two springs on opposite spokes, both for greater security and because you can get more play with two than with one of twice the strength.

158. But there is a more common and much cheaper kind of maintaining power for turret clocks, which goes by the name of the *bolt and shutter;* in which a weight at the end of a lever is made to drive one of the wheels in the train for a few minutes. The drawing at p. 209, though it is not intended to represent the common construction, will serve to explain it. The lever A B C D carrying a weight at its end turns on an arbor A, and at B there is a bolt or click (shown as a *fixed* bolt in the drawing), which will allow the lever to be raised, but not to fall again without turning the great wheel with it. This bolt is more commonly made to slide in a socket, like the spring bolt of a door; but this is a bad plan, as it is very liable to stick, and then the clock is left without any maintaining power. On the long arm of the lever there is placed a cap or

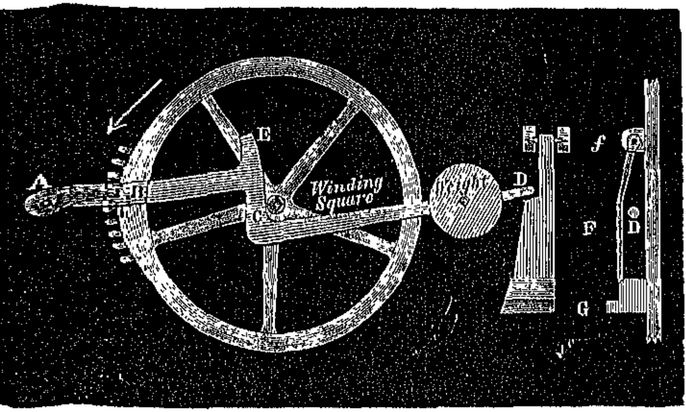
shutter (different from that shown in the drawing) which covers the winding square C when the lever is down or not in action; and therefore the man has to raise the lever and shutter out of the way, before he can put the winder on. The bolt is generally made to act on the centre wheel because that requires a less weight; but where the dial work is driven independently by the great wheel, as in § 150, this is objectionable, because it causes the centre wheel pinion to act backwards: if it is inconvenient to apply it to the great wheel it would in this case be better to apply it to the hour-wheel which is driven by the great wheel. And in any case it is to be remembered that the maintaining power only acts until it has run the bolt out of gear, and drops on to the stop G, or some convenient part of the clock frame, and it will of course run itself sooner out of a wheel that turns in an hour, and still more out of one that turns in about twenty minutes, than it will out of the great wheel. It might indeed be made to act longer by setting the lever upon an arbor concentric with that of the wheel or nearly so, and making the click throw itself out by coming against a pin in the frame when it had got low enough; but the more simple and safer way is to make it act on the great wheel as the clock weight does.

But the great defect of all the common methods of constructing the bolt and shutter is that you have no security for the lever being raised far enough to keep it in action during the whole time of winding up, especially if the man loiters over it, as he is very likely to do in winding a large clock with a heavy weight. There is also a smaller defect of just the opposite kind, viz: that the maintaining power generally remains in action for some time after the winding is done, and so there is a double force on the clock. This does not happen with a spring going barrel; and though that may also theoretically run itself down if the man is too long winding, yet practically it can hardly happen, because if he stops to rest he will of course let the weight go off his own hands on to the clock, which will at once restore the tension of the spring, and he will begin winding again with the same maintaining power as at first. Indeed in a clock that takes several minutes to wind and has a spring going barrel, it is better to direct the man always to stop and leave hold of the winder in the middle of the winding.

But, on the other hand, it is impossible to make the spring act with equal force during the whole time. In clocks of the common construction this is of very little consequence, for the spring is only required just to keep the scape-wheel going, as a heavy pendulum will go for many minutes without any sensible variation, even if it receives no impulse at all from the scape-wheel. But in a clock with a remontoire in the train, which always requires a certain amount of force to lift or wind it up, it is evident, that if the spring is to be strong enough to do it when it is nearly run down, it must act much more strongly than is necessary at first; and the larger the clock, or the longer it takes to wind up, the greater must be the excess of force to be left constantly on the clock train, in order to bring the spring to the requisite tension; which, though it will not reach the escapement, being intercepted by the remontoire, is of course a defect, and helps to wear out the clock;

and therefore the spring-going barrel is not so well adapted for a remontoire clock as some kind of maintaining power which acts by gravity, and so is pretty nearly constant. Mr. Airy's going-barrel, which will be described in § 160 effects this object; but it so enormously increases the expense and trouble of making the clock, and is so unfit to leave in the hands of any but skilful persons afterwards, that it is impossible that it can ever be generally used. I have therefore attempted to contrive an improved bolt and shutter, which shall be capable of acting for a much longer time than can possibly be required for winding, and yet can be thrown out of gear as soon as the winding is done (which the common bolt and shutter cannot, without opening the clock-case), with a provision to secure its being so thrown out; and which will also have the more important advantage of rendering it absolutely impossible to begin winding without previously raising the lever to the full height it is intended to go. All this can be done by a very simple addition to the common bolt and shutter, and in a manner which supersedes the necessity for any sliding bolt or click.

159. The bolt B is now, as it appears in the drawing, merely a fixed tooth on a short arm of the lever, and it is put into or out of gear with the great wheel, by sliding the arbor A backwards or forwards in its pivot holes. The shutter CE is no longer a cap covering the winding square when it is down, but a circular arc, whose centre is A, and which comes close up to the winding square, so that when the arbor A is pulled forwards, or out of gear with the wheel, you cannot get the key or winder on. And

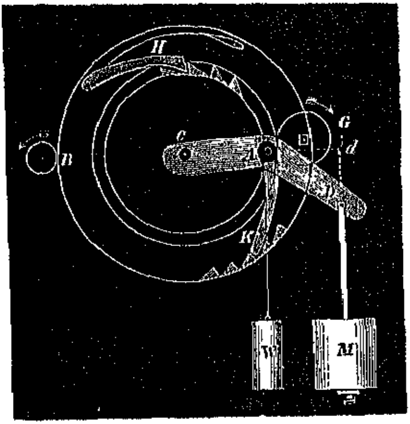


in order to prevent the lever from being merely pushed back, without being properly raised, its end D, or another arm projecting from it in any convenient place, rests, when the lever is out of gear, in front of the stop F (which will be further described presently), so that before you can push the lever back, you must lift it over the top of F, and then push it back, and so into gear; after that you can put the winder on, and as the clock goes on the lever falls, and the end of it descends *behind* the stop F, as shown in the side view of *f* F G. Now F*f* is a kind of flap or valve turning on a hinge at *f*; and it will be seen, on looking at the side view of it, that you can, when you have done winding, pull the lever D forward, with its arbor, which will pull the flap forward; and then the bolt being out of gear, you will let the lever drop in front of F on to the block G below it, and the flap immediately falls back, so that you cannot get the lever back again by the way it came out, but it must go over the top of F, as at first, when you want to wind up again.

The reader may be inquiring, what will happen if the man omits to pull the lever out of gear: *the clock will stop* in five or ten minutes, as the lever will hold it fast. This is so done on purpose, for it might be very easily avoided by making the bolt a click, as before; but then you would have no security for the lever being properly thrown out of gear when the winding is done, and being left in such a position that the man cannot begin winding the next time without raising it. I had originally designed it with a self-acting inclined plane behind F, to throw the lever out of gear as it descends; but, on the whole, I am satisfied that it is better to omit that provision, as it would encourage carelessness in the man who winds; for he would probably never take the trouble to pull the lever out of gear, if he knew it would do so itself in a few minutes, and consequently he would always leave the clock with the double force on; which he would take care not to do if he knew the clock would immediately report his negligence by stopping. It is obvious that this apparatus can be applied as easily to any other wheel as the great wheel, though, for the reasons I have mentioned, I prefer that wheel. Where the going part winds up by a jack-wheel, as I have recommended (141) for large clocks, even when not absolutely necessary, the shutter CD might be put merely behind that wheel, so as to prevent it being pushed back without first raising the lever; and then pulling the lever out of gear would, at the same time, throw out the jack-wheel, and is no more trouble than doing that alone, as is done in the apparatus which I must now describe.

MR. AIRY'S GOING-BARREL.

160. This maintaining power was originally invented for the great equatoreal-telescope-driving clock at Cambridge, which has a revolving pendulum (16), and therefore will not bear even the momentary disturbance of putting on and taking off an ordinary bolt and shutter, though the force is very nearly uniform when it is on. It is applied to the Exchange clock, and is intended by Mr. Airy to be applied to the great clock at Westminster.



The construction of it is curious, and will require some attention to understand the principle of its action. The barrel arbor C is not set in the clock frame, but in a swinging frame, of which one side is C A D, and which turns on pivots of its own (not an arbor going through the frame) at A, and is kept balanced between the weight M which is hung to it as shown in the drawing, and the clock weight W with the weight of the barrel and its wheels, as follows. The pivots A are so placed that C A = the radius of the barrel. The reason why the sides of the frame are not straight will be explained afterwards: *d* is the point where

M would hang, if the sides were straight, or where C A produced meets M D produced. At B is the pinion of the centre wheel. Now, since the clock weight W hangs by a line passing through A, we may suppose the whole as a rigid system (there being a proper contrivance to make it do so) to turn round A for a short time, and we shall then have $M\frac{A\,d}{A\,B}$ as the force of M upon the pinion B; but this is diminished by the weight of the barrel and its wheels, which we may call N; and their centre of gravity being C, they will produce a force on B the other way $= N\frac{C\,A}{A\,B}$. If therefore we suppose for convenience A d to be made = A C, the force upon B when the system all turns round A will be $(M-N)\frac{A\,C}{A\,B}$. And we want this to be equal to the force exerted by the weight W when the barrel and wheel turn round C as the fixed point, which is $W\frac{A\,C}{B\,C}$: therefore, in order to find what the weight M must be, we have the equation $\frac{M-N}{A\,B}=\frac{W}{B\,C}$ $\therefore$ $M=N+W\frac{A\,B}{B\,C}$.

Suppose, for example, that N = 1 cwt., W = 2 cwt., and the diameter of the barrel is half that of the wheel, or $\frac{A\,B}{B\,C}=\frac{3}{2}$; then M will have to be 4 cwt. The way in which the machine is all made to turn round A while winding up, or while the weight W is taken off the clock, is this: there is a click K fixed to the frame C A D at A, and working in an internal ratchett of the great wheel, of which a few teeth are shown in the drawing; the common barrel ratchett H being fixed to the great wheel.

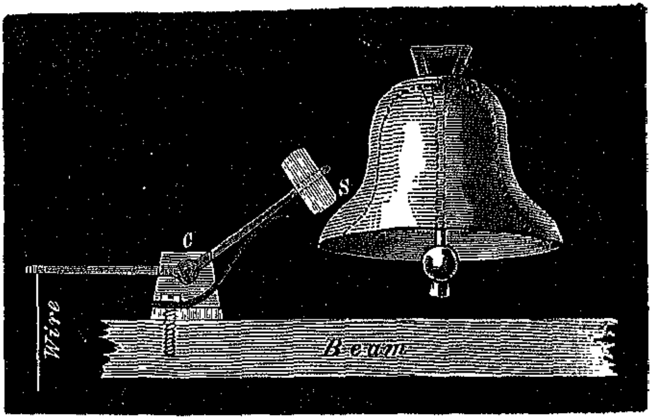
The clock is wound up by a jack wheel G, working into a wheel set on the end of the barrel as in other large clocks;

the jack wheel arbor is placed on a level with C A, and therefore the point of contact A of the two wheels may be considered a fixed point, and the whole system is still balanced upon it while winding. The arm A D is made oblique, in order that if the equilibrium between M and W should be deranged by the friction of the pulleys or other causes, it may speedily restore itself, a small motion of the point D causing a sufficiently large alteration of the length of A *d*, or of the *moment* of M. A *d*; whereas if C A D were a straight line, this *moment* would not be sufficiently changed until the frame had moved through a large angle, and probably run itself out of gear altogether. It will now be easily understood that this machine must be exceedingly expensive and troublesome to make and fix; though the mere elevation or section of it in this drawing gives no idea of the additions and alterations which it renders necessary in the clock frame and the rest of the train. And after all, however useful it may be for a clock with a revolving pendulum, it does no more for a clock with a vibrating pendulum, and especially one with a remontoire, than a common bolt and shutter, which does not cost one fiftieth part as much as this did in the Exchange clock, provided only you can make sure of its being properly applied; which, as I have shown, may be done very easily and cheaply.

STRIKING PART.

161. The striking part of a church clock is much the same as that of a house clock, except in the position of the hammer, and its acting by its own weight instead by a

spring. The shape of large bells being not hemispherical, but of the shape in this drawing, the thick part S or *sound bow*



of the bell is so curved, that a tangent to it would make an angle of about 35° with a horizontal plane: and therefore the axis C of the hammer must be so placed that C S will form that angle with the horizon. As in house clocks the hammer is prevented from jarring on the bell by a spring as shown in the drawing.

Now it is evident that a hammer resting in this position, and rising in a circular arc, requires more force to raise it at the beginning than at the end of its motion. But as striking pins of the common construction must begin to act at some distance from the end of the lever which they raise, their force is *less* at the beginning than the end of the motion, and so a good deal of the force of the clock is wasted, and the hammer is not raised nearly so high as it might be if the action were uniform. As regards the hammer, we may remove this inequality in a great degree by putting it on a long shank, as it will then rise a given height with less angular or circular motion, and consequently with less waste of power in the train which raises it, and it will also fall with less friction on its pivots, and therefore greater velocity. And as regards the striking pins, we must make them of such a shape that they do not begin to act at some distance from, but at the end of the lever: that is to say, they must be of the form called *cogs* or *cams*, of which the curve is to be determined by calculation or experiment, so that the lever may always act only upon its end, and with a sliding and not a scraping friction between the two surfaces.

162. Now raising a lever by *cams*, or *cogs*, or *wipers*, is a different thing from driving a wheel, though it may appear to be the same thing; and I may as well warn any reader of the common translation of 'Camus on the teeth of wheels,' that the rule for the construction of cams given in the Introduction (which is not Camus's) is entirely wrong, from overlooking this difference: it would be right if the end of the lever were a round pin. In *wheels*, when a tooth of the 'driver' has driven a tooth of the 'follower' to a certain distance, they leave each other, and the motion is taken up by another pair of teeth; and when the two teeth part company, the end of the driving tooth is pressing against the side of the driven one, and not at its end, as the teeth O, *c*, in the drawing at p. 138; whereas a cam raising a lever must finish with the point of the cam at the end of the lever. Therefore the curve of the cam must, firstly, be such that it will remain acting upon the end of the lever all

the time, instead of beginning at the end, and then going farther up, as in a wheel, and then sliding back again; and secondly, with a view to diminishing the friction, the curve must allow the end of the lever to move upon it *as a tangent* through the whole motion; and in that case, if the lever wears at all, it must still wear itself as a tangent, and will therefore never change its proper form, if the end of the lever is made a circular arc round the centre on which it turns.

163. The curve which would do this accurately is called in mathematical language a *tractrix*, because of the mode in which (theoretically speaking) it can be described. Practically however that method cannot be made to answer; neither is there any other convenient way of describing it, as far as I know. But it luckily happens that a curve of the same nature as that which is required for teeth is sufficiently accurate for any such angle as a hammer lever has to move through, though it would not do for large angles.* It will be found by any one who makes the calculation, that there will be no appreciable error, for angles up to about 30°, if t be the length of the lever or tangent, a the radius of the circle upon which the cams are to be set, and r the radius

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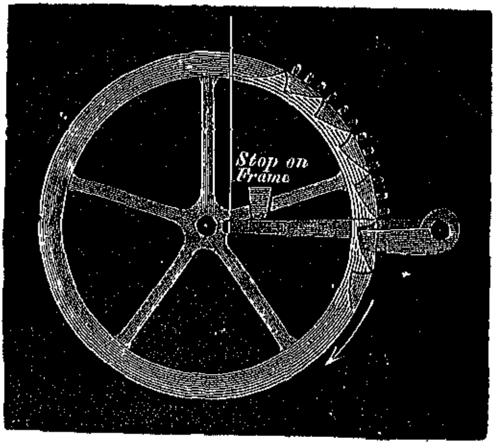
* I may remark that this curve does not raise the hammer with quite uniform velocity, but rather more quickly at the beginning. The difference however is very small, and is of no consequence; for as the train always has a little run before it begins raising the hammer, it has more momentum at first. In fact, a clock made in the common way will often not be able to start itself, if the wheels are so placed that the lever is left just resting on a pin when it has done striking, for want of the momentum acquired by the run previously to encountering the resistance of the hammer.

of the circle which is to generate the epicycloid by rolling on the circle of rad. a, and r is determined from the equation, $2r = \sqrt{a^2 + at} - a$.

For example, suppose $t = 4$ inches, and $a = 8$, then r will be ·9 inch, or rather less than a quarter of the length of the lever; and it will not be much affected by changing the value of a to a moderate extent. These are the sizes of a and t in a large clock which Mr. Dent has lately made for Tavistock church, in which this construction was adopted. There are 24 cams on the wheel of the hour part, and 36 on each side of the great wheel for the quarters. The hour bell weighs 30 cwt.; and though the wheel with these cams on it is of cast iron, and their surfaces are not polished as pins always are, the striking weight is only 2 cwt., with a fall of about 60 feet, which every clockmaker will recognize as much less than usual for eight-day clocks striking on much smaller bells. This arises partly from the shape of the cams, and the short run of the lever upon them, and partly from their being on the great wheel instead of the second wheel, and in some degree also from the cams acting on the lever on the same side of its axis as the hammer wire, being what is called a lever of the third order; for in that case the pressure on the axis, which produces the friction, is only the *difference* between the pressure caused by the weight of the hammer, and that of the cams, instead of being the *sum* of those pressures, as it is when the clock and the hammer are both pulling upwards at opposite ends of the lever.

164. The striking part of the Tavistock clock, that is, the same patterns of the wheels, is adopted also in the Mean-

wood clock, which has a bell of only 11 cwt. It may be supposed that the same wheel cannot be right for a bell of 11 cwt. and one of 30 cwt. Perhaps if it had been necessary to make a new pattern, it might have been made of 15 inches diameter instead of 18, but certainly not less, or it would have made the spaces for the cams inconveniently small. And the extra size and weight are of no consequence in the first wheel of the train, especially as the rope pulls upwards. The result is that by adopting this arrangement of the cams and a cast iron wheel, one pattern will serve to produce wheels fit for a bell of 11 cwt., and also a great deal stronger than the old-fashioned wheel which raises the hammer of great Tom of Lincoln. As I believe this kind of wheel is new I have given a separate drawing of it, showing a few of the cams, and the lever.



But although the exact value of *a* in the above equation is immaterial for the purpose of determining the shape of the epicycloidal cams, we have still to find out at what depth the cams must be placed, so that their points may just come up to the bottom of the teeth of the wheel, which must be the boundary of the cams. For this purpose cut out in tin or paper a pattern of one of the cams of greater length than will be required, and also cut on the tin an edge representing a tangent from the bottom of the cam, which will be a radius of the great wheel, and prolong it to a point T at the distance *t* from the bottom of the cam; and cut out also on the same piece of tin an arc of the circle which will be described by the lever *t* round T (leaving a piece of the tin at the junction of the cam and of the arc sufficient to hold it together). Then draw on a board a circle about ⅛th of an inch larger than the bounding circle and divide it according to the number of the cams. Take the tin pattern and slide it about on the board, taking care always to keep the edge which represents the radius of the wheel in a radial position, until you see that a portion of the cam and of the lever-arc is just included in one division of the large circle.

The place where the point T falls on the board will then give the exact distance of the centre of the lever arbor from the centre of the wheel: and another circle drawn on the board of the exact size of the bounding circle will cut the points of the cams at the proper place; and their backs should be cut away in circular arcs drawn with a radius a little longer than *t*. The reason why the first circle was drawn on the board rather larger than the actual bounding circle was to allow the lever to fall off one cam a little *before* the next is ready to receive it. And it must be remembered that the length of the lever must not be altered from the length *l*, nor the position of its centre altered from that determined as above; and the face of the lever must be in the straight line or plane joining the centres of the wheel arbor and the lever arbor. If any more space is required to clear the lever in its fall, it must be taken off the back of the cams and not off the end of the lever, as it is very tempting to do, or they will no longer work together without scraping; in fact the lever had better be too long than too short; and the end of the lever should be an arc of a circle described round the centre of its arbor, as it will then always keep the same length as it wears.

Even if epicycloidal cams are not used, neither small pins nor rollers should be used; but the pins should be cylinders large enough for their action to begin as near the end of the lever as may be, and half the cylinder should be cut away (as indeed every letting-off pin should be) to let the lever drop suddenly as soon as it has reached its highest point; which rollers prevent, causing the drop to begin slowly, whereby part of the rise, and the power of the clock, is wasted. The acting face of the lever should be not less than half an inch broad for a large clock, for the same reason that broad teeth are better than narrow ones; a narrow lever cuts nicks in all the pins in a very short time. And in order to take as much pressure as possible off the pivots of the arbor on which the lever is fixed, the two arms of the lever should be as close together as they can be placed and not one at one end of the arbor and the other at the other; and all the cranks, if any are required, should have long arms, in order to diminish the angular motion required for a given rise of the hammer; and there should be as few cranks as possible.

165. I have described a simple method (20) of trying what force any given escapement is really using, or how much of the going weight is employed in merely overcoming the friction of the train. It may be ascertained by a still more simple method, how much of the striking weight is lost by friction, and the motion of the train between every two blows, and by the hammer lever and cams being so arranged that nearly all the power is consumed in raising the hammer the first inch. It appears that the hammer shank, or rather the line from the axis to the face of the hammer, generally makes an angle of about 35° with the horizon. Since we cannot help some force being lost by the rise taking place in a circular arc instead of a straight line, though the radius of the arc ought to be made as large as possible, we may, in comparing one clock with another, assume the hammer to rise in a straight line at an angle of 35° to the vertical. Therefore if H is its weight (beyond what is required to balance the rod work, strictly speaking), and d the rise from the bell, the work done by the hammer in the day is $156\,\text{H}\,d \cos 35°$; and if h is the actual fall of the clock weight W in n days, $\frac{\text{W}\,h}{n}$ is the work it *ought* to do in the day if no force were lost; and the ratio of these two quantities will show what proportion of the power is lost. $\text{Cos } 35° = {\cdot}82$, and if d is expressed in inches and h in feet, and n is eight days, the above ratio will be very nearly $\frac{85\,\text{H}\,d}{\text{W}\,h}$, which, if there were no loss of power, would be a ratio of equality. It will be found

however that it is seldom as much as ½, and often as little as ⅓, in clocks that strike from the second wheel. In the Exchange clock it is rather more, because it has cams, not pins. In a table given of five existing clocks among the parliamentary papers respecting the Westminster clock, the only one, even if those that strike from the great wheel, that gives this ratio as high as ⅔ is the one in Wilton Place (St. Paul's, Knightsbridge), which is a clock with cast iron wheels and cams; not like the Tavistock wheel, but with ten cams on each side and two hammers raised alternately. In the Tavistock clock the above ratio is as high as ¾; or only ¼th of the power of the clock is lost in friction and the necessary interval between the hammer falling and beginning to rise again.

166. It is mentioned in one of the parliamentary papers that in some foreign clocks the hammer is placed with its head downwards and its axis near the top of the bell; so that it is easier to raise at the beginning than at the end of the motion. This is no doubt an advantage when the hammer is raised by pins which begin to act at some distance from the end of the lever; but it must be remembered that a hammer so placed will require a much larger angular motion than one placed as usual to raise it to the same vertical height, on which the force of the blow depends, and not merely on the distance from the bell to which it is raised; for it will be seen on looking back at the drawing of a bell that the hammer shank must stand at a much larger angle with the horizon than 35° when the hammer head is downwards, and moreover it will strike the proper part of the bell more obliquely, since the angle of 35° (or

thereabouts) is adopted just because it is that which enables the hammer to strike the bell as directly as possible.

When the bell is not required to be swung, the hammer might indeed be set at the proper angle by putting the head upon a sort of double shank embracing the bell. But, as has been shown just now, we can get quite sufficient rise out of a hammer set upon a shank of proper length in the common way, with no greater loss of power than $\frac{1}{4}$th; a great part of which must, under any construction, be lost in the necessary interval between the fall of the hammer and its beginning to rise again, and in the inevitable loss due to the hammer spring; and therefore I think we may be more profitably employed in improving the construction of the clock itself than in making or adopting contrivances to meet a defective construction.

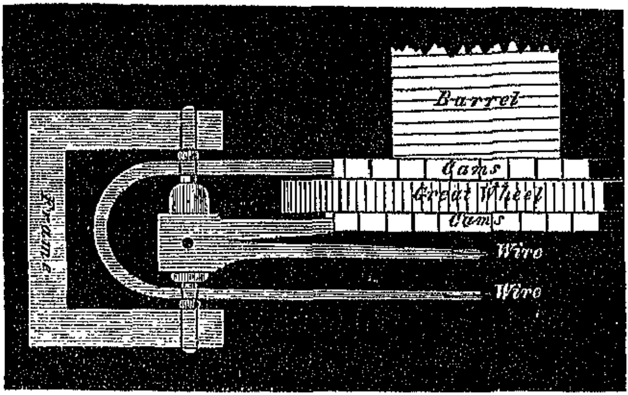
I think however that it is a question worth considering, for a stationary bell, whether it would not be better to make it stand with its mouth upwards, that the hammer may strike it on the inside, as the clapper does. No clock-hammer ever gets such a sound out of a bell as the clapper does when it is ringing in full swing. It is not improbable that the bell opens under a blow more freely than it closes: a blow on the inside makes the circle open in that part for its first vibration, whereas a blow on the outside is resisted by the bell as an arch.

I may mention that a stiff hammer-spring, which allows the hammer to stand very near the bell, is better than a weaker one, which admits of larger vibrations, and therefore requires the hammer to be kept farther off. I have much increased the sound of a house clock with an unusually large bell and hammer, by substituting for the common stop-spring a thin piece of vulcanized India-rubber, set upon a firm stop just below the hammer-head. Moreover, the hammer ought to have a broad face, and not, as some clock-makers fancy, a sharp one. Besides the inferiority of the sound, I remember a very large and fine bell being cracked by a hammer set so as to strike with its edge.

QUARTERS.

167. When the clock strikes quarters, the striking wheel is made in the same way as the hour striking wheel, only with cams or pins on both sides of the wheel, of the proper number for each hammer to strike 120 times in the twelve hours instead of 78. The cams on one side should not be set half way between those on the other, but the cam that raises the second hammer should be behind the other by about one-third of the distance between two successive cams on the same side, in order that the interval between the two blows of each quarter may be half that between each successive pair of blows. In this case I suppose both the levers to ride upon one arbor, which is a better arrangement than putting them on different arbors, one below the other. In the Tavistock clock, the two levers are arranged as shown in this drawing, in order to bring both their long arms into the most advantageous position. I have not thought it required to show the moveable bushes, which are necessary to enable the arbor of the two levers to be passed through all the four holes in the frame and levers.

In all cases, both for the hour and quarters, there ought



to be a strong stop (if cast on the frame all the better) for the *long* arm of the levers to strike against when the hammer falls, to take the shock off the striking pins, and, as far as possible, off the arbor. Such stops are often put to the short arm, and much too weak, and too near the arbor.

The quarter bells should be the 1st and the 4th or 5th of a peel of 8, the hour bell being the 8th. Where there are less than 8 bells, quarters may struck at every quarter except the 4th; and this will only require 72 blows for each hammer in the twelve hours.

168. Wherever there is a peal of ten bells, the quarters may consist of chimes like the well known chimes of St. Mary's at Cambridge, or that (in my opinion) very inferior 'improvement' of it at the Royal Exchange, for which, however, it is right to state that the maker of the clock is no more responsible than for the bells, about which there has been so much discussion. The bells used for such chimes are the 1st, 2nd, 3rd, and 6th of a peal of six, or (which is the same thing) of a peal of ten, the 10th

being the hour-bell. It cannot be done with a peal of eight, because the first six do not themselves form a peal; and the 4th of a peal of eight is a very miserable substitute for the 6th of a peal of ten; though it is adopted in some places, as at St. Clement's church, in the Strand; and I could mention a clock made for a nobleman a few years ago, who intended to have the Cambridge chimes, but the five bells had been cast of the notes for a peal of eight before the clockmaker learned (on asking me to furnish him with the proper changes) that the bells would not make those chimes at all. To prevent such mistakes in future, I will state what the chimes are, both of the Cambridge and Exchange quarters, and the construction of the barrels to produce them:

	Cambridge.			Exchange.	
2d	3126		1st -	3126	- 2d
	3213	4th	3d -	6213	- 4th
	1326			1326	
3d	6213			3213	
	1236 - 1st				

The Cambridge barrel turns twice in the hour, having only the five changes set upon it, and the number of them to be played at each quarter is determined by the locking-plate, which turns once in the hour. The barrel must first be divided not into 20 but 25 equal parts, and every fifth division left without a pin in it, in order to allow twice as much time between two successive changes as between two successive notes of the same change. In the Exchange chimes, the reader will see that each quarter begins with the same change, and therefore, though there are only four changes altogether, yet the barrel must take the whole hour to turn in, and must have 40 pins in it, instead of the 20 required for the Cambridge chimes. And consequently, besides the inferiority in the tunes played by the Exchange clock to those of St. Mary's, you cannot tell what quarter it is until you have heard out the whole tune; whereas everybody in Cambridge knows directly a quarter begins what it is going to be, except that the hour begins with the same changes as the half hour.

Chimes of this sort are so much better than the common ding-dongs, and so much easier to distinguish, at least when they have a different tune as well as number for every quarter, that it is to be hoped the present plan of the great Westminster clock will be altered; and that as the hour bell is intended to be the largest ever made in England, viz. 14 tons, so its quarters, if they cannot be superior to all others in tune as well as size, will be at least equal to the best that are known. Eight bells, which were proposed by Mr. Barry, are too many for distinctness as a quarter chime, and so would cause great additional expense for no good. Mr. Whitehurst suggested five; but those are very inferior to the Cambridge four.

BELLS.

169. As this subject of bells is materially connected with that of church clocks, I will add a few remarks upon it. And first, I may observe that it is sometimes a question whether a clock should be made to strike on the tenor bell of the existing peal, or upon a little bell to be set upon the top of the tower. When the tenor is a large

bell, there can be no doubt that it has much the best effect to strike on that. But then it generally requires a larger and more expensive clock; and unless the tenor is a bell of at least 10 cwt., a small one of two or three cwt. outside the church will frequently be heard farther, and accordingly that plan is sometimes advantageously adopted.

170. Where the bells are not ready made for the clock their size is of course optional; but unfortunately their quality is not equally at the option of the purchasers. And in consequence of the disputes which have occurred respecting the Royal Exchange bells, I wish to suggest to those who have to give judgment on bells, that the *tune*, that is to say, the note of one bell relatively to others, is a totally distinct thing from the *tone*, or absolute quality of the bell, and of infinitely less consequence; because the note can easily be altered sufficiently, but the tone of a bad bell can never be mended, except by breaking it in pieces, and melting it; and not always by that, if the metal has been bad originally, or the bell-founder does not know how to make a good bell. In order to judge of the absolute goodness or tone of a bell, what is wanted is not so much musical knowledge or perception of tune as experimental knowledge of what bell-metal is capable of. A peal of cast iron bells might be made perfectly in tune, and to a person who had never heard bell-metal bells, would appear a perfect peal. No rules can be given to enable people to judge of the quality of sounds; but a few things may be mentioned as necessary to attend to; such as, whether the bell sounds freely on being lightly touched; how long it 'holds the sound,' compared with other known bells of about the same

size, and of good quality; and particularly whether on filing or polishing the bell anywhere the metal appears perfectly close and free from holes. If it does not, you may be sure the bell is a bad one, without any further examination, and it ought to be condemned at once. A bell may also be too thin for its size, and perhaps occasionally they are made too thick. In bad bells, it may be frequently observed that you hear a harsh metallic sound of the knock of the hammer, independently of the continuous or ringing sound, which alone ought to be heard. Other points must be left to the discretion of the judge.

As many persons may have read some remarks on the relative merits of the great bells of St. Paul's and Christ Church, Oxford, in one of the Parliamentary papers, I must say that I do not agree with them; on the contrary, I think St. Paul's far the best of the four large bells of England, though it is the smallest of them, being about 5 tons; while York is 12, Lincoln 5½, and Oxford 7½, which last is a remarkably bad bell. There is a general opinion that bells cannot be made now equal to the old ones. It is true that bells improve in sound for a few months, but no more; and they only alter in loudness, not in the quality of the tone. The badness of many modern bells is due not to want of age, but to want of skill or attention in the founder. I have seen as bad bells as need be, with dates of about 200 years ago; and the best I ever heard (for a small peal), at Castle Camps, in Cambridgeshire, were made about 20 years ago by a country bell-founder, of the name of Dobson, who however did not meet with sufficient encouragement, and lately died a pensioner in the Charter House;

and many excellent bells, both large and small, were cast by Mr. Mears, and his predecessors, Messrs. Leicester, Pack, and Chapman, at the well-known foundry in Whitechapel, which for some years has enjoyed nearly a monopoly; I have lately however seen some very good bells, made by Messrs. Taylor of Loughborough; and I have had the opportunity of comparing one of their bells with a foreign one imported by Mr. Dent for trial, and the English one was decidedly the best. And therefore, though the casting of bell-metal is a 'mystery' requiring considerable skill and management beyond merely melting together certain quantities of copper and tin, there is no reason to reckon bell-founding yet among the *artes perditæ*. If people would always reject bad bells, good ones would soon become as common as they ever were.

TIME OF STRIKING FIRST BLOW.

171. It is usual to make the quarters let off the hour; that is, the locking-plate of the quarters is furnished with a pin or a snail which, while the last quarter is striking, performs the office of the discharging pin on the hour wheel of the going part when there are no quarters. And for ordinary clocks this plan does well enough; but it is evident that in that case you cannot rely on the first blow of the hour, which is the proper indication of the exact time, being right to several seconds, because it depends on the rapidity with which the quarters may happen to strike, in addition to the ordinary sources of inaccuracy in the time which the hour train takes to get into action; both of which

differ considerably in different states of the clock. And therefore in some clocks there are two snails set on the hour-wheel, one of which lets off the quarters, from a quarter to half a minute before the hour, and the other snail lets off the hour striking part exactly at the hour. And here I may remark, that the larger the snail is the more accurately it will let off, because the linear space on its circumference corresponding to one beat of the clock will be larger, but the more friction it will cause. Moreover, if the time of striking the first blow is intended to be very accurate, the hammer should be left on the lift, or just on the point of falling, instead of having to wait while the train is raising it. And in that case (and indeed it is better to do so whether the hammer is left on the lift or not) there should be a small click applied to one of the wheels of the striking train to prevent it going backwards when the clock is being wound up. Mr. Dent uses merely a single pin, set as a tooth into the fly arbor, and so placed that the click falls against it when the clock has done striking.

TRAIN REMONTOIRES.

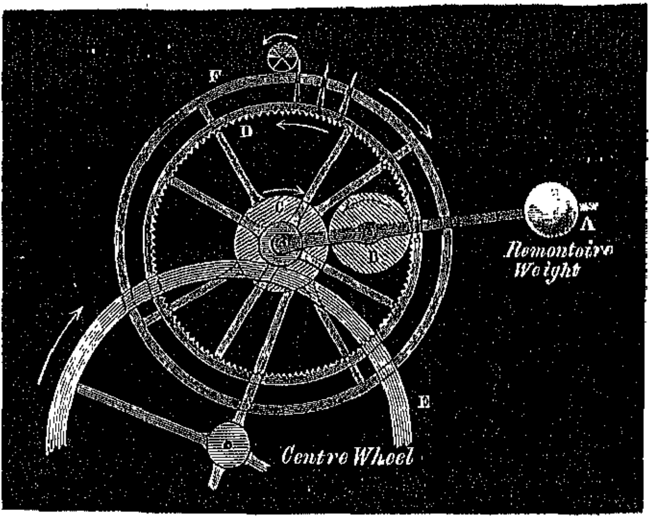
172. This naturally leads to the subject of *remontoires in the train,* which I have several times referred to, and which are quite distinct from remontoire escapements. If the scape-wheel, instead of being driven directly by the train and the clock weight, is driven by a small weight which is wound up at every twenty or thirty seconds by the clock train, the clock will have these advantages: 1st, The

scape-wheel will be driven by a force as nearly uniform as possible, being free from all the inequalities of the friction of the train and dial work, and the effect of the wind upon the hands. 2ndly, The striking may be let off more exactly than in the common way, because the snail will turn through a fifteen times larger angle if let off by the remontoire every thirty seconds than by the pendulum every two seconds; and so you may be quite sure that the striking will be let off at the sixtieth second of the sixtieth minute of the hour, which you cannot secure in the common way. 3rdly, The long hand will move a visible distance by jumps at every half minute, which will enable a spectator to observe the time as accurately as from the second-hand of a regulator; whereas in common turret clocks the time can hardly be taken to less than a half a minute even in the most favorable positions of the minute-hand. In short by the use of a remontoire in the train a clock would go better, and would also be available as a regulator both by sound and by sight, as perfectly as an astronomical clock; while a common turret clock, if it goes ever so well, is useless for very exact observations, such as a person wanting to regulate a good clock of his own would require, as he can neither tell the time from the hands nor rely on the striking to several seconds.

173. There have been various contrivances for this purpose. One is described by Reid as having been put up by him at Edinburgh in the last century, which was worked by a Huygens's endless chain (79). He says it went very well, but that the chain and other parts connected with it wore out so fast that it was removed. There have been

many attempts at it in France, but they are stated in French books on the subject to have been generally unsuccessful. However a public clock with a remontoire in the train has now been going for five or six years in London; and the efficacy of it as regards time keeping may be judged of by any of the numerous chronometer-makers who live within sound of the Exchange bells; and any person may judge of the effect of it as regards the other objects I have mentioned by looking at the long hand just before it strikes the hour: he will see the last jump of the hand, after the quarters have done striking, take place at the same moment as he hears the first blow of the hour. And as the great clock for the new palace at Westminster is to have some contrivance of this kind, a description of it will probably be interesting.

Any person with a moderate amount of ingenuity will see that the only real difficulty in the problem is to keep the action of the remontoire weight on the scape-wheel while it is being lifted. Harrison's going ratchett might of course be applied; and although it would cause a small amount of friction, it would have some advantages perhaps over the one I am going to describe. The plan of the Exchange clock remontoire is this, omitting some merely mechanical details. The wheel D, whose pinion is driven by the centre wheel E, has internal teeth; and a wheel C, which rides upon the arbor of D, has external teeth as usual. On the arbor of D there rides also an arm or lever C B A, carrying the remontoire weight A; and there is (or may be considered to be) a pin or stud upon the arm for a wheel B to ride upon, which works between the external teeth of C and



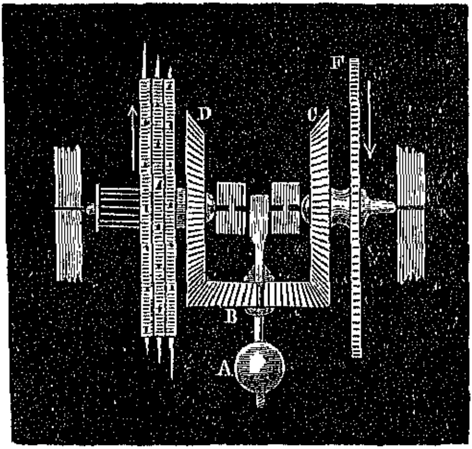
the internal teeth of D. Consequently, whenever the wheel D is driven by the train it will raise the right side of B, which will raise the lever and the weight; but the left side of B will nevertheless be always pressing downwards on C and tending to turn it the opposite way to D; and therefore a large wheel F fixed to the wheel C may be employed to drive the scape-wheel, which will then be driven merely by the remontoire weight and not by the clock train.

174. The mode of letting off the train at every twenty seconds is this. The scape-wheel arbor turns in a minute and is nearly half cut through in three places near together; and on the rim of D, which is made broad enough for the purpose, are placed three sets of spikes in different planes corresponding to the three nicks in the scape-wheel arbor; and these three nicks being made at angles of 60° to each

other, they come successively at intervals of twenty seconds into such a position that a spike of one set can pass through the corresponding nick, but a spike of the next set strikes the arbor in a place where it cannot get through for twenty seconds more, and then a spike in the third plane is stopped in the same way, and so on. Thus at every twenty seconds the wheel D is allowed to move through the space between two spikes, and so the little weight A is raised through a small space by the force of the clock train, and the force on the scape-wheel is the same upon the whole for every successive third part of a minute, though during the twenty seconds it varies a little as the distance of A from a vertical line through C varies, by reason of its describing a circular arc.

Half a minute would be a better interval than twenty seconds, because it is not easy to see at a distance whether the hand is ten seconds before or after the half minute, and the motion at each move would also be half as much again for thirty seconds as for twenty.

175. The plan which is adopted in the French turret clocks, which I understand are now generally made with a remontoire in the train, is the same in principle, only instead of a wheel running between the internal teeth of one wheel and the external teeth of another, a bevelled wheel riding on the remontoire arm runs between two other wheels at right angles to it, as shown in the next drawing. The wheel D performs the office of the internal wheel D in the Exchange clock, raising the weight A by means of the wheel B, which turns freely on the remontoire arm, and so always presses downwards on C, to which is fixed,



as before, the wheel F which is to drive the scape-wheel; and the broad wheel, with the three rows of spikes in it, is fixed to D, as before. I do not know that either of these methods is better than the other, except that, as it is impossible to cut bevelled teeth to the right shape as truly as flat ones, there is probably rather less friction in the internal wheel plan than in the other; but it is also the more expensive of the two.

But there is this objection to both of them, that the spikes strike the scape-wheel arbor with considerable force, and even while they are at rest press upon it pretty heavily, and therefore a larger force is required to drive the scape-wheel. The force of the blow has been somewhat diminished in the Exchange clock by putting a spring with a concave face for the spikes to slide up before they reach the arbor. In the more recent French clocks, it is done by making the train drive a fly, which moderates its velocity; and in some of them the spikes are put on the end of the fly, or an arm on the fly arbor, which is a very great improvement, as it also diminishes the constant pressure and friction on the arbor of the scape-wheel, in the ratio of the velocity of the spikes when set on the second wheel to their velocity when set on the fly. They have also been made to let off by a lever like a striking part, instead of by nicks in the arbor; but that method gives the scape-wheel more to do, and produces much greater friction. This however would not signify where there is a remontoire escapement as well as a remontoire in the train; and perhaps for a very large clock with such an escapement this might be found the best way of letting off the train remontoire, since in that case the pressure or blow of the spikes is immaterial, as it does not fall on the scape-wheel arbor.

CONTINUOUS MOTION REMONTOIRE.

176. A very ingenious and curious application of the gravity remontoire has lately been made by a French clockmaker, named Wagner, for the purpose of obtaining a continuous motion of the heavy part of the train combined with the accuracy of a vibrating pendulum driven by a constant force. Instead of the remontoire being let off at definite intervals by the scape-wheel, the bevelled wheel D works a fly, by the intervention of two or three intermediate wheels. This fly revolves horizontally below the clock frame, for a reason to be explained presently. If the fly always turned at a constant and proper rate, it would evidently let the driving wheel D turn one way just as much as the opposite wheel C turns the other way, under the action of the escapement and the remontoire weight, in any given number of seconds; or, in other words, those two wheels between

them would always keep the remontoire arm at the same height. Now this arm is prolonged to a convenient length, and from its end is hung, by two wires, a thing like a *gong*, suspended horizontally, and with a hole in the middle for the fly arbor to pass through; and this gong, or bell, is so placed, that when the remontoire is at its medium height the bell about half covers the fly, which turns within it: if the remontoire falls below its medium height the bell will evidently fall, and more completely enclose the fly; and the effect of this is that the air within the bell becomes rarer by the action of the fly, and consequently offers less resistance to the fly, which will therefore regain its proper velocity; and of course an increased velocity of the fly is identical with an increased velocity of the train, which was previously going too slowly to keep up with the regular motion of the scape-wheel. And in like manner, if the train and fly are going too quickly, the bell is lifted up, and the fly more exposed to the external air, which offers an increased resistance, and so again restrains the velocity.

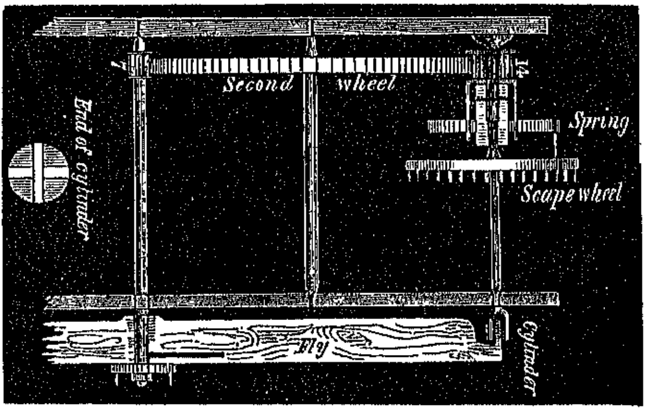
There is indeed, *theoretically*, a much more simple way of combining a continuous motion of the train with a vibrating pendulum. For if any point in a heavy pendulum is connected by a long horizontal rod with a crank, or a pin set on the face of a wheel, moving in the same plane as the pendulum, and the pendulum is made to swing just so far as to let the crank turn round in one double oscillation, it may be easily proved that the natural velocity of the given point in the pendulum is the same in every position as the velocity, in a horizontal direction, of the end of the crank, the crank itself revolving uniformly. The practical difficulty, however, is to keep the pendulum always vibrating the same arc, when there is a variable force acting on the crank, without which it would not answer.

SPRING REMONTOIRE.

177. Instead of a weight acting on one of the wheels of the train, as in any of the preceding methods, a spring may be used to communicate the force from the pinion of the scape-wheel, or the wheel below it, to the wheel itself. And a spring possesses these great advantages over a weight, that it requires no maintaining power to keep it in action when winding up, as I explained in the case of a spring clock without a fusee (80), and that it acts without any friction. These advantages are so great, that I have no doubt a spring remontoire may be made better, and it may certainly be made cheaper, than any gravity one.

There is a description of a spiral spring remontoire let off by nicks and spikes, as before described, in the Encyclopædia Britannica. And I have lately seen some small French clocks with a spring remontoire on the second wheel, and I am told at Mr. Dent's they go better than ordinary French clocks without a fusee, which, however, is not saying much for them. The spring should, if possible, be put on the arbor of the scape-wheel instead of the second wheel, because then it acts without any friction of the scape-wheel pinion; in fact, the scape-wheel then has no pinion, properly speaking.

But all the remontoires of this kind that I have seen or read descriptions of, are liable to the objection that either the wheel or its pinion rides upon the arbor of the other of them, as in Mr. Airy's escapement (47), which causes the wheel to turn with considerable friction; and from this and other causes, the spring remontoires that have been hitherto made, especially in turret clocks, do not appear to have given satisfaction. I shall therefore describe one which has been lately made, and in which the objection I have just now mentioned is removed, and some other advantages obtained, and which is perfectly easy to construct, and at a moderate expense.



The large wheel in this drawing, which is the second or centre wheel (there being only three in the train) drives a pinion of 14 leaves, which rides on a stud or fixed arbor screwed into the clock frame; and the pinion is also prolonged into a pipe large enough to enclose, without touching, the brass bush, which is fixed on the end of the stud to form a pivot-hole for the scape-wheel arbor. On this pipe is fixed a spiral spring, (the mainspring of a moderate-sized musical box), of which the outer end takes hold of a pin set on the back of the scape-wheel. It is evident therefore, that if the pinion and pipe are turned round or wound up from time to time, it will wind up the spring, and the scape-wheel will be driven by the spring without any friction at all, except that of its own pivots; and also that whenever the second wheel is let go, it will so turn the pinion and wind up the spring.

The letting off is not done in the same way as in the Exchange clock, but the wheel drives another pinion (marked 7) on an arbor which carries a fly; and this fly, (though not so exhibited in the drawing) may have at its ends the spikes which are to slip through the notches in the scape-wheel arbor as before described. Now, assuming the scape-wheel to turn in two minutes (which is more convenient than one minute for turret clocks) and the remontoire to be let off every half minute, the letting off would be done by a four-armed fly set on a pinion of the same number as the scape-wheel pinion, and four notches in the scape-wheel arbor acting as the three do in the Exchange clock. But I have also made an alteration in this respect, for the purpose of diminishing still further the pressure of the spikes on the scape-wheel arbor, and getting a larger motion of the fly in proportion to the same motion of the train, and consequently a slower motion of the train during its action. The scape-wheel arbor comes through the frame and ends in a cylinder, of which the face has two nicks cut across it, one broad and ¼ inch deep, and the other narrow and ½ inch deep; and therefore if one end of the fly has a short and broad pin properly placed, it can slip through the broad nick only; and a long and thin pin at the other end of the fly will slip through the narrow nick only, when the nicks respectively come into a position at right angles to the fly. In this way the two-armed fly is allowed to turn half round at every quarter of a revolution of the scape-wheel; and as the fly pinion has seven pins while the other has fourteen, the remontoire spring is wound a quarter round at every let off of the remontoire. The second wheel, which drives them both, turns in eighteen minutes, and consequently if the spikes were set on it instead of on the fly, their pressure on the scape-wheel arbor would be 36 times as great. I found this pressure amount to barely two ounces, with a very heavy weight on the clock; and as it is made to act upwards, it only relieves the pressure of the arbor and the cylinder on the adjacent pivot-hole.

The spikes or pins are not really set on the end of the fly, but on bent springs about three inches long, in order to diminish the force of the blow on the scape-wheel arbor, and the too sudden stoppage of the train; and for the purpose of doing the same thing more completely, and also stopping the recoil of the fly after the blow, there is a friction spring set on the frame, which the fly has to slide over just before it reaches the cylinder; this of course diminishes its velocity or momentum when it is greatest, and also acts as a click which the fly cannot pass in recoiling.

It remains to be explained how the adjustment of the remontoire spring is made, in case it is found to give too much or too little force to the scape-wheel. The fly is not fixed to its arbor, but it has a click that takes hold of a ratchett with ten or twelve teeth, fixed to the arbor in the usual manner of the striking fly ratchett. Therefore when you want to alter the tension of the spring you have only to lift the click, without stopping the clock, and shift the ratchett as many divisions as may be necessary, which will turn the scape-wheel pinion and spring just half as much as you turn the fly arbor, since the scape-wheel pinion has twice as many pins as the fly pinion. The ratchett is made with square teeth, which are also numbered, for greater safety of action and certainty in adjusting it. The spring must of course be occasionally cleaned and oiled, to keep it from rusting, and so should the pendulum spring.

This is the construction of the clock represented in the frontispiece, which is just completed for the newly built church at Meanwood, near Leeds. It is of course too soon as yet to give any account of its performance as regards time-keeping, but its mechanical action is quite satisfactory; and as that is the only novelty in it, the principle of the spring remontoire having been tried for some time, I see no reason to doubt that it will be altogether successful. The going weight required is about half as much again as it would be if there were no remontoire, because all train remontoires require additional weight to overcome the additional friction, and to wind up the remontoire without any hesitation; but as none of this additional force reaches the escapement it is of no consequence, and you can put on weight enough to drive the hands in all weathers without at all affecting the swing of the pendulum; whereas in a clock without a remontoire you cannot put on weight enough to drive the hands in bad weather and when the oil is frozen, without making the pendulum swing too far as soon as it becomes warmer. I have seen the semi-arc of the pendulum of a church clock, and a very good one, vary nearly a degree between winter and summer.

Another effect of this remontoire is the remarkable silence of the beat, as compared with the Tavistock clock in which the wheels are of the same size, or with the Exchange clock in which the momentum of several wheels and the remontoire weight has to be stopped by the pallets at every beat; whereas in this clock the only thing to be stopped is the scape-wheel, which is less than four inches in diameter and only moves $4\frac{1}{2}°$ at each beat. It is probable also that it follows the pallets more closely when moved by a spring than when moved by gravity. This silence of course indicates that there is less waste of force at each beat in a clock with a spring remontoire of this kind than either without any remontoire or with a gravity remontoire.

178. I have hitherto spoken of the *horological* advantages of a train remontoire. But it has besides the *economical* advantage of superseding the necessity for highly finished wheels in the lower part of the train, as it reduces that part merely to a machine for driving the weight of the hands and winding up the remontoire, instead of being a machine for transmitting to the pendulum as uniform a force as possible. And therefore I see no reason why the great wheel, hour-wheel, and all the leading-off or bevelled wheels (of which sometimes as many as nine are necessary) should not be of cast iron instead of brass, which it seems would almost cause their cost to be measured by shillings instead of pounds. If it had been certain beforehand that this new remontoire would answer, the Meanwood

clock would have been so made. I know that there is a prejudice against cast iron clock wheels even in the striking part. But people would easily see that this prejudice is unfounded if they would only remember that the striking part of a clock is nothing but a machine for raising a heavy hammer 156 times in a day, or rather in ten minutes, since it would strike 156 in about that time if allowed to go on; that all you want is sufficient force to do this without any unnecessary wear of materials; that (as I have shown) cast iron clocks are now doing this work with considerably *less* waste of power and therefore less wear of materials than the best brass clock probably in the world; and lastly that such clocks can be made much cheaper than brass ones equally good. And when the going part is also reduced, as it is by a remontoire, to a mere weight-raising machine in which uniformity of force is of no consequence, there will be no more necessity for brass wheels there than in the striking part. The only question was whether a remontoire could itself be made at a moderate expense; and it now appears that it can; indeed I was led to turn my attention to the contrivance of such a remontoire by a remark of Mr. Dent's, that a good and cheap remontoire was essential to any further material improvement in turret clocks, especially large ones; and it may be added that a good (that is, a secure) and cheap maintaining power or 'going-barrel' apparatus was equally essential to the making of such large clocks except at an enormous increase of their cost, and I think that difficulty has also been removed as described in § 159.

179. I have spoken throughout of *brass* wheels;

meaning thereby either brass or *gun-metal*, which is a compound of copper and tin instead of copper and zinc, with a lower proportion of tin than in bell-metal. The proportions for the best gun-metal are, I understand, from 92 copper + 8 tin to 90 copper + 10 tin; and such metal is harder than the best hammered brass, and yet not too brittle for the teeth of wheels. It is however a difficult metal both to make and to work: the castings, especially large ones, being often full of defects, consisting not only of holes, but of hard pieces which are as destructive to wheel-cutters as a cinder in a piece of bread is to human teeth; and it is in any state a very tough metal and clogs the files. I am informed however by the best authority on this subject, that these defects in the casting may be prevented by not putting the tin to the copper at once in the above proportions, but previously making an alloy of 2 copper + 1 tin, which they call 'hard metal,' and which is the 'highest' compound the metals admit of without the excess of tin beginning to make the alloy softer again: to this alloy the further proportions of copper are afterwards added; and in order to obtain the greatest density or specific gravity which the compound admits of, the castings are always made with a long 'dead-head' to produce considerable pressure on the fluid metal. I am told also that adding a very small quantity of zinc, about 1 per cent., makes the metal both more fluid in the crucible and more compact when cold. The specific gravity of metal cast in this way at Woolwich has been known to be as high as 9, and is generally about 8·75, while that of brass is only 8·37 (according to the 'data' in Weale's Dictionary).

180. I think it is also worth the consideration of clockmakers whether they could not get more true and sound castings, either of brass or gun-metal, and such as would suffer less waste and require less labour in squaring out and turning up, by having cast-iron moulds made for the sizes of wheels they are in the habit of using. Large castings, even in brass, are often defective for as much as $\frac{1}{10}$th of an inch deep; and I understand a very sharp and clear casting can be obtained from a heated iron mould instead of a damp sand one, since it does not chill the metal too soon but lets it run into the smallest corners. The part of the mould between the spokes would have to be made separate and bevelled a little, so as to lift up, and let the wheel contract in cooling, or it would probably break itself; and the mould should not be an open one, but close, and with a longish pipe to it, by way of a 'dead head,' to produce pressure upon the metal, as the effective part of bells, viz., the mouth, lies at the bottom of the mould. These however are only suggestions, which some person better versed in the art of brassfounding may perhaps reduce into a more practical shape. The necessity of some improvement in this art will be evident when I state that three brass castings were made for the great striking wheel of the Tavistock clock before one was obtained sound enough even to cut for the model; and more, I believe, for the great wheels of the Exchange clock, which are of gun-metal, as those of the Parliamentary clock are required to be, in my opinion very unnecessarily as regards all but the escapement part of it, in such a large clock: I mean of course that they should be of iron. This difficulty of getting really good gun-metal

castings, hard enough to be any better than brass, causes some clockmakers to prefer well-hammered brass to such gun-metal as they can be sure of obtaining from the founders. At any rate however the bushes, which are too thick to be hardened throughout by hammering, and in which brittleness does not signify, ought to be made of gun-metal; but it should be free from hard bits, which would probably cut the arbors. It must not be forgotten, moreover, that gun-metal is more expensive than brass, both in the making and the working.

181. Lastly, all the iron work, whether cast or wrought, and whether visible or invisible, except just the acting surfaces, ought to be painted. Polishing it does no good, costs money, and requires continual cleaning and oiling to keep it from rusting. This rule has been followed throughout in the Meanwood clock, though it is one in which, as the reader has seen, no expense was spared that was thought likely to produce any useful effect.

And with regard to this rather important matter of oiling, fresh oil ought never to be put on, especially on the escapement, without thoroughly wiping the old oil off. I have had to take out a scape-wheel and wash it with soda to get off the accumulations of oil with which an attentive sexton had lubricated it in the course of two or three years. The pivots should have clean oil whenever they appear to be dry; but the pinions should only be wiped with an oily cloth, and not have oil dropped on to them, as is the common practice; and this applies to house clocks as well as church clocks. As far as my experience goes, I think no oil equal upon the whole to some which was recommended to me at Mr. Dent's for the purpose of preserving steel surfaces from rusting: it is neat's foot oil, well-stirred about in water, skimmed off and filtered once or more through blotting paper until it is quite clear. Though it is the most filthy looking stuff at first, it produces at last an oil more fluid than the best sweet oil, and which has the important advantage of never freezing, nor forming a brown cake on iron, as the vegetable oils do; I should think, therefore, it is peculiarly suitable for church clocks: indeed I have applied it to a house regulator for some time, and, as far as I can judge, with very good effect.

182. The pulleys for church clocks require more attention than they frequently receive, especially as the fixed pulleys are often put high up in the tower, where the oiling of them is neglected. Every pulley ought to be as large in diameter as it conveniently can be made, for the obvious reason, that the larger it is the slower it has to turn. I should say that no pulley for a moderate sized clock ought to be less than nine inches diameter, nor less than twelve inches for a large clock with heavy weights. Another point, which is of perhaps even more importance, is, that the pivots, or arbor, should be fixed into the pulley, and not a pin put through a hole in the pulley, as the common pulleys for raising weights are made, in which, for various reasons that I need not specify, it is of less consequence than in clocks. For when the pin goes through a hole in the pulley, it requires to be much thicker than pivots turning in bushes set in the frame, in order to obtain the same strength; and therefore the friction is greater, and the weight required to drive the clock greater,

and the wear of the pin and the hole in the pulley greater than it need be. Secondly, the effects of this wearing are much more mischievous; for pivots always pressing in one direction only wear a hole larger in one direction, or make it longer, and it will therefore work in it with no more friction at last than at first; whereas when the hole in a riding pulley is worn bigger, the friction is increased as much as if the pin had been originally made so much larger; and indeed more, because the bearing surface of the pin is narrower than if it were as large as the hole. Lastly, a fixed arbor, with brass bushes screwed into the pulley frame, keeps the pulley much steadier, and with more equal bearing on both sides, than a pin. Pulleys made as I have described of course cost rather more than those made in the common way, but they are very well worth the additional expense.

183. There are two or three other matters which should be attended to in putting up church clocks. One is to enclose them in a wooden box that locks up, leaving the winding squares open, so that the clock can be wound without unlocking the case, and so that nobody but the person who has the care of the clock can get at the works. The pendulum should also be enclosed all the way up. And it is essential to the keeping of a clock in good order that the place where it stands should be light: if it is not light already, it should have a window put in before the clock is put up; and if the architecture will not allow it anywhere else, the middle of the dial may be, and often is with good effect, made a window. When the clock is a good one, worth looking at, it is a good plan to have some

small panes of plate glass put in the doors of the box or case, so as to show the escapement and the regulating dial, which, if the clock stands in the belfry, will serve also for a dial for the ringers. If the bottom of the pendulum comes in a convenient place, it is as well to put a piece of glass to show the degree plate, so that anybody can see how far the pendulum is swinging. All these little things tend to make people careful of their clock when they have got a good one. Mr. Vulliamy mentions several public clocks in Paris which are fitted up with glass, so that they can be completely seen without opening them; and the same thing has lately been done at the Exchange clock, and is contemplated by the astronomer royal for the Parliamentary clock.

184. Not long ago, I heard that the weight of a church clock in London had broken the rope and fallen (as a weight of several cwt. easily would do) through the belfry floor and the pavement of the church into the vaults below. This accident, which is not very uncommon, is most likely to arise from the sudden stoppage of the weight when it is wound up until the sexton feels he can wind no farther; and with the view of stopping him in time, a string may be put to each weight and over a small pulley at the top, and the other end, with a little weight attached to it, made to come down close by the place where the clock is wound up; so that when the great weight is up, the little weight is down, and the man will know that it is time to stop winding. This is like the weight put to an organ to show the blower when the bellows are full. Where the weights come down on to a floor over the heads of people in the church,

it is prudent to put a large box filled with wool or sawdust on the floor, where they would fall; the wool or sawdust need not be left open, but should be covered up with boards, which will only break first if a weight falls.

THE GREAT CLOCK FOR THE NEW PALACE AT WESTMINSTER.

185. I have no doubt that it will be interesting both to clockmakers and to other persons to know what has taken place up to this time with regard to what may be called the National Clock, both on account of the building on which it is to be placed, and because it is intended to be the best and largest public clock in England, and in the world.

Six years ago, viz. in March, 1844, Mr. Barry, the architect of the new Houses of Parliament, wrote* to Mr. Vulliamy, to ask if he would furnish him with a plan for the clock; and as he could not undertake that Mr. Vulliamy should be employed to make it, he inquired upon what terms he would furnish the plans, first, in the event of his being employed to make the clock, and secondly, of his not being employed. Mr. Vulliamy, in reply, proposed that, if employed, he should be paid 100 guineas for the specification, calculations, working and other drawings; and if not employed, an additional 100 guineas for his time and trouble.

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[*] I may as well state that I shall follow the words of the correspondence as nearly as I can conveniently, and without perplexing the reader, printer, and myself, by continual quotation marks, and interruptions of them.

Shortly afterwards Mr. Barry wrote to the Board of Woods and Forests, saying that, owing to the progress making with the clock-tower, it was desirable to have the necessary specifications, working drawings, and *estimates* prepared; and that he had therefore applied to Mr. Vulliamy as, *in his opinion*, the person best qualified to make out such specification, working drawings, and estimates; and he forwarded the two preceding letters, and recommended that Mr. Vulliamy's offer be accepted. In a few days he received an answer from the Board conveying to him the requisite authority to engage Mr. Vulliamy upon the service, and upon the terms named in Mr. Barry's letter. This was of course communicated to Mr. V., who replied that he should proceed without delay to prepare the plan of the clock for Mr. Barry's inspection.

In January, 1845, however, Mr. Vulliamy wrote to Mr. Barry, to say that he had just observed a mistake in the letter from the Office of Woods and Forests, viz., that though Mr. V. had said nothing about an estimate, the Board had incidentally introduced the word, no doubt as a matter of course; and that to make an estimate would, until it is definitely settled how the clock is to be made, be quite useless; and would be a work of great labour, occupying much time, and not contemplated either by himself or Mr. Barry; and that he thought it right without delay to notice the circumstance, lest it should give rise to any misunderstanding afterwards.

To this letter there appears to have been no answer from Mr. Barry, or notice of it by the Board, except so far as the subsequent letter of Mr. Barry, of July, 1846, is an answer.

In November, 1845, Mr. Dent wrote to the Board, to say that he was desirous of being admitted as a candidate for supplying the large clock, and such others as might be required for the new Houses of Parliament; and by way of recommendation he referred among other things to the testimonials of the astronomer royal and Mr. G. Rennie, respecting the Exchange clock, and proposed to obtain the sanction of the Board for erecting the new clock, subject to the approbation of the astronomer royal, with Mr. Barry, and Sir John or Mr. George Rennie, as referees. The Commissioners answered that when the drawings and specifications for constructing the great clock were completed and could be submitted to the several clockmakers who might be applied to, as the basis upon which their tenders were to be founded, the Board would include him as one of the competitors, for making that as well as any other clocks that may be submitted to competition.

To this Mr. Dent replied, that if adherence to drawings and specifications to be prepared by another clockmaker were to be stringent on him, he must decline to become a candidate; that he should feel it a duty to comply with any suggestions from the astronomer royal, but could not engage to act under the directions of authority less eminent, or to follow instructions, which by degrading him to the position of a mere executive mechanic, would prove detrimental to his reputation.

Apparently in consequence of this letter, though after an interval of some months, Lord Canning wrote to Mr. Airy, to ask his opinion, as it was of importance that the clock should be *the very best that the science and skill of the* *country can supply,* whether the best means of obtaining such a clock would be to call upon some of the most eminent clockmakers to send in specifications, drawings, and estimates, of the clock which each would recommend and would be prepared to make; or whether it would be better to place the matter in the hands of some one experienced mechanician, and to adopt the *description of clock* which he might recommend, leaving the *execution* of it open to tender; and he requested the astronomer royal to send him the names of the persons or person he would recommend for the service in either case.

Mr. Airy replied that a nearly similar question was addressed to him in 1843 by the Gresham Committee with respect to the Exchange clock, and that he then replied that certain conditions ought to be laid down, which he would furnish, and that the clockmakers' plans should also be submitted to him for his opinion, and that the Committee should refer to him for a certificate at the completion of the work: that those conditions were adopted by that Committee; and that the result is that a clock has been put up, which is superior even to most astronomical clocks, and possesses these rare advantages, that the first stroke of each hour is correct as to time within less than one second, and that a person standing on the pavement can take time from the face without an error of a second. Mr. Airy therefore proposed that a similar course should be followed here. He says that he suggested to the Gresham Committee the names of Mr. Vulliamy and Mr. Whitehurst; but, *by arrangements with which he was not acquainted,* the work was placed in the hands of Mr. Dent, chronometer-maker (*i. e.* before that time not a turret-clock maker); and he was bound to say that Mr. Dent had carried out his views most completely, making in the mechanical arrangements which he (Mr. Airy) had suggested some judicious alterations, which received his entire approval. Under all the circumstances, considering that a new clock pretending to a degree of accuracy equal or superior to that of the Exchange, must probably contain some of Mr. Dent's inventions, and would at any rate be improved by his experience, that the trust is, so to speak, confidential, and that there is no such thing as a market for such clocks—Mr. Airy thought it would probably be the best course to transmit proposals (including his enclosed conditions) to Mr. Dent, and to ask for his tender; and if his price should not be excessive, that he should be employed: if it appeared objectionable, other makers should be applied to; but he thought only the two he had named.

The Board did not however adopt Mr. Airy's recommendation to apply in the first instance to Mr. Dent; but Mr. Barry a few days afterwards, in July, 1846,* wrote to Mr. Vulliamy to inform him that the Board had determined to invite the tender of plans and specifications from different quarters for the clock; to be based upon the enclosed general conditions prescribed by the astronomer royal, who (Mr. Barry stated) had recommended that application should be made to Mr. Dent and Mr. Whitehurst as well as to Mr. Vulliamy. He also informed Mr. V. that if he should have acquired any information which might lead him to suggest a departure from the enclosed conditions he was at liberty to do so in sending in his plans. And further that the Board considered it convenient that he should submit the *estimated cost* of supplying and completing the clock in all respects according to the conditions.

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* It may be observed that just at this time Lord Canning resigned, and was succeeded by the present Lord Carlisle.

186. The following are Mr. Airy's 'Conditions to be observed in regard to the construction of the clock.

'1. The clock frame is to be cast-iron, and of ample strength. Its parts are to be firmly bolted together; where there are broad bearing surfaces, these surfaces are to be planed.

'2. The wheels are to be of hard bell-[gun-] metal, with steel spindles working in bell-metal bearings, and proper holes for oiling the bearings.* The teeth of the wheels are to be cut to form on the epicycloidal principle: [nothing is said about the pinions, of what shape or material they are to be.]

'3. The wheels are to be so arranged that any one can be taken out without disturbing the others.

'4. The pallets are to be jewelled.

'5. The escapement is to be dead-beat, or something equally accurate, the recoil escapement being expressly excluded.

'6. The pendulum is to be compensated.

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* This is a mistake: such holes are unnecessary and mischievous, as they will let in dust, which will do more harm to the pivots than want of oil would, and clock pivots can be oiled perfectly well without holes. In heavy machinery going with considerable speed, and requiring a great deal of oil, the case is different.

'7. The train is to have a remontoire action, so constructed as not to interfere with the dead beat principle of the escapement.

'8. The clock is to have a going fusee [barrel. No particular kind of going barrel is here specified, but it appears from the subsequent papers that one similar to that in the Exchange clock is intended.]

'9. It will be considered an advantage if the external minute-hand has a discernible motion at certain definite intervals of time.

'10. A spring apparatus is to be attached, for accelerating the pendulum at pleasure during a few vibrations: [this will be explained presently.]

'11. The striking machinery is to be so arranged that the first blow for each hour shall be accurate to a second of time.

'12, and 13, [relate only to a possible electrical connexion with the Greenwich Observatory for the purpose of making the clock report its own behaviour to the astronomer royal.]

'14. The plans before commencing the work, and the work when completed, are to be subjected to the approval of the astronomer royal.

'15. In regard to articles 5 to 11, the maker is recommended to study the Exchange clock.'

188. An explanation will probably be required of the apparatus referred to in the tenth of these conditions. It is evident that a clock with a two seconds pendulum cannot be altered by any less amount than two seconds, without handling the pendulum in a manner which is both difficult

and unsafe with a heavy pendulum. Mr. Airy therefore contrived for the Exchange clock an apparatus which enables it to be set to any fraction of a second. It consists of a long spring set upright upon a frame which slides under the pendulum bob, and is so arranged that by pulling a string in the clock room the frame can be brought into such a position that the spring hits the pendulum at every swing in one direction, which accelerates its vibration a little. Therefore, if the clock is a few seconds too slow, the man merely pulls up the string, and holds it till he observes the second-hand and the beat of the clock agree exactly with that of the chronometer in his hand. If it is a few seconds (not an even number) too fast, it is first put back one beat too much, and then accelerated to make it right.

I may observe here, that a clock should never be altered by taking hold of the pendulum anywhere but at the bob; and indeed it is better not to meddle with the pendulum at all, but to put the clock back by holding the scape-wheel carefully for as many beats as may be necessary, if it is too fast; and if it is too slow, by first putting the hour wheels forward by their adjusting work (150) and then stopping the scape-wheel; and you may put the scape-wheel back the time of two beats in one, if instead of merely holding it steady you make it escape the wrong way. In regulators, which always have a second-hand, the best way of retarding the clock a few seconds is to put your finger firmly on the seconds dial, just before the hand when it is *dead*, so as to stop it for the proper number of seconds. If it is less than a minute too slow, you must first put the minute-hand forward a minute, and then stop the second-hand.

188. At this point the Westminster clock correspondence begins to assume rather more of personal than of horological interest, of which however I shall divest it as far as possible. But it is necessary to the understanding of the matter to state that Mr. Vulliamy answered Mr. Barry's letter, enclosing these conditions, by declining to enter into a competition, chiefly on the ground that he objected to the astronomer royal as sole referee, because he considered other individuals as well, if not better qualified to offer an opinion on the subject; and secondly, because Mr. Airy had shown himself prejudiced in favour of Mr. Dent, by having publicly stated, through the Gresham Committee, that he 'had no doubt the Exchange clock was the best public clock in the world;' and in a subsequent letter of March, 1847, to the same effect, he refers also to a letter of Mr. Airy's to Mr. Dent, saying, 'I shall state without hesitation that I consider you the most proper person to be entrusted with the construction of another clock of similar pretensions.' On which it is obvious to remark, that whether the recommendation of a man to make a second piece of machinery, because he had already made one of the same kind to the satisfaction of his employers or their referee (who had not recommended him) is what is commonly understood by the word 'prejudice,' or not, Mr. Dent had got no benefit from Mr. Airy's recommendation that he should be employed, because the Board did not adopt it; and he thenceforth stood in exactly the same position as Mr. Vulliamy and Mr. Whitehurst.

In the following month Mr. Vulliamy sent to the Board, through Mr. Barry, his drawings and specifications;

adding, however, that he had not prepared any estimate, for the reasons stated in his previous letter on that subject, and for the further reason that it would be useless, since he had declined to make the clock under the direction of the astronomer royal; and concluded by thanking Mr. Barry for the very honourable and friendly manner in which he had been treated by him throughout the business.

Mr. Vulliamy also, at the same time, availed himself of Mr. Barry's invitation to offer such suggestions as occurred to him for departing from any of Mr. Airy's conditions, and suggested a departure from no less than half of them; and, in fact, did not assent to one of them which was not in accordance with his own previous practice. Mr. Vulliamy's description of his own plans occupies 27 folio pages; and therefore, though they might be interesting to clockmakers, it is impossible to make any use of them here, or, I may add, of the other specifications, descriptions, &c., on account of their length. Mr. Airy's opinion of them all I shall have to state presently.

There was some farther correspondence about a card-board model, which Mr. Dent offered to furnish by way of illustrating his plans, but which Mr. Vulliamy rightly said was only throwing away time and money. In the letter in which he declined to furnish such a model, he repeated his objections to Mr. Airy, and added, that in several public cases of reference of horological *inventions* the reference was not to an individual but to a committee. Instead of the card-board model, Mr. Vulliamy informed the Board that he was then making for Mr. Peto a quarter clock of rather more than one fourth of the size of the great clock, and that he was purposely making it as like the great clock as was practicable. I have myself seen this clock since it was finished, and it is a very handsome and well-executed piece of machinery; and in like manner the Exchange clock might be looked upon as Mr. Dent's model, though not intended to be exactly followed.

Various communications took place between Mr. Airy, and Mr. Whitehurst and Mr. Dent, respecting the details of the clock, and finally they both sent in their tenders, drawings, &c., which were, together with Mr. Vulliamy's plans and observations, submitted to Mr. Airy; and he also went to make a personal inspection of Mr. Dent and Mr. Whitehurst's factories, and in May, 1847, reported to the Board to the following effect. That as regards their factories and tools, either of them, with some assistance from an engineer's establishment for the large frame and the great wheels, is competent to undertake the work. That Mr. Dent's experience, previously to his commencing the manufacture of turret clocks when he undertook that of the Exchange, had been chiefly in astronomical clocks and chronometers, in which he had been compelled to pay the utmost attention to the excellency of fine workmanship and to secure great accuracy of results; and that since he commenced the manufacture of turret clocks he appears to have entered in an enterprising manner into that business, examining the construction of foreign clocks of celebrity, and making himself acquainted with the literature of the subject. That Mr. Whitehurst has had very considerable experience in the manufacture of turret clocks, and is enthusiastically fond of clockmaking; but he has seen none but English clocks, and those principally in a limited district. That if it were necessary to entrust the making of the clock without any control to one or other of them he should prefer Mr. Dent; because he thinks it easier for him to acquire Mr. Whitehurst's solidity than for Mr. Whitehurst to acquire Mr. Dent's accuracy; but that under the most trifling control, either of them will certainly construct the clock in a perfectly satisfactory way. Lastly, he notices the two estimates, which were, Whitehurst, £3373; Dent, £1600. He says that it is out of his power to explain the astonishing difference between them. It is not of much consequence to the public what the explanation is; but Mr. Airy suggests, first, that Mr. Dent may really be able to do the work at less cost to himself than Mr. Whitehurst (I suppose from his previous experience in the Exchange clock); and secondly, that he may be willing to construct the clock, even at a loss to himself, for the sake of the reputation which he hopes to acquire by the making of such a clock, while Mr. Whitehurst has made his estimate at what is called a paying price. Mr. Airy (naturally enough after what had occurred before) declined to offer any further suggestion as to which of the two candidates should be employed.

He added in a separate letter some remarks upon Mr. Vulliamy's plans and papers, as they had been submitted to him by the Board with the others, although he considered it impossible that Mr. V. could be employed to make the clock, as he refused to comply with the proposed conditions. He says that in regard to the provisions for strength, solidity, power, and general largeness of dimensions, the plans are excellent; but that in delicacy they fail, and fail so much that he considers that such a clock (except of course as to its size) would be a village clock of very superior character, but would not have the accuracy of an astronomical clock. The meaning of which is, that there are no provisions in the clock proposed by Vulliamy for securing greater accuracy of going, striking, or indicating the time, than in a village clock of the ordinary construction but of superior workmanship. With regard to the personal objections to himself, Mr. Airy says that Mr. Vulliamy's demand for a committee is not borne out by the instances he had cited; because in all those cases the question was about the introduction of principles, which if established were to be applied to an infinite number of instances; whereas here there is no new principle: the instance is unique: its effects are only those of the display of a good specimen of the present state of the art: that (besides the similar case of the Exchange clock) Mr. Airy is often requested by persons in want of chronometers to recommend makers of them; and, finally, that Mr. Whitehurst, a *bonâ fide* competitor, had made no objection to him as referee: in fact, he acknowledges in his letters to the Board, that he had received valuable information from the astronomer royal.

Since this report upon the plans in May, 1847, nothing more has been done about the matter, except that on the Board being reminded of their letter to Mr. Dent, Mr. Barry was stopped from ordering any more of the smaller clocks of his own authority, as he had done for the House of Lords.

Many other remarks on the personal questions that have been very unnecessarily introduced will have occurred to the readers of the correspondence, or even of this abstract of it; but as they are of no importance to the science of horology, I shall leave the reader to make them for himself. I will only add, for the information of those who have no other means of knowing it, that none of the gentlemen proposed by Mr. Vulliamy as referees have given, to the public at least, any reason for believing that they have paid any particular attention to the subject of clockmaking, which, as to all the most important parts of a clock, is a perfectly different thing from engineering. And though I do not agree with the astronomer royal as to some of the details of the plans suggested or approved by him, I have no hesitation in saying that, unless his 'general conditions' are substantially followed, the clock will not be what it ought to be, and what both the First Lords of the Woods and Forests have declared that it was intended to be. Indeed, unless it is so made, it will be a mere waste of money to make it at all, as there are plenty of clocks in that neighbourhood for all the ordinary purposes of public clocks, though they are of no use for the extraordinary purposes for which this clock is intended, and is really wanted, and which it will answer if properly made, but not otherwise.

It is satisfactory to be able to add that, if it is really to be ever made, and made properly, there will be no reason to regret the delay that has taken place, because in the mean time some experience has been gained which will enable a better clock to be constructed than that contemplated in the plans which were settled three years ago, and at quite as little expense.

ON PUBLIC CLOCKS.

189. The gratification of the curiosity of the readers of this book on the subject of the Westminster clock was not the only object of giving this history of it. I wish also to point out to individuals and public bodies who want to procure really good turret clocks a few things which they ought to attend to, but hardly ever do. Of course, very few such clocks as the Westminster or the Exchange clock are wanted; but as much as three or four hundred pounds is sometimes spent upon a clock for a large town, which is, after all, not equal to the cheapest 'regulator,' which may be bought for 25 guineas. Instead of spending a large sum of money upon such a clock, if not the best than can be made, it would be in every way better to get a large and strong clock for half the money, and a pretty good regulator with it, and make the clockmaker who has the care of it set it by the regulator every day if need be; or what would be still better and cheaper, a dipleidoscope (9), by which the clock can be corrected *independently* every day when the sun shines at noon. The truth is, that what the astronomer royal said of the great clock may be said with nearly the same truth of clocks very far short of that in accuracy—'there is no market for such clocks.' Plenty of clockmakers will contract for them and make them, no doubt fairly and honestly enough as regards the quantity of labour expended on them; but very few indeed,—so little demand is there for such things,—really know all the particulars on which labour is worth expending, and on which it is not.

There is a very sensible remark in one of Mr. Vulliamy's letters (which it was unnecessary to refer to for any other purpose) to the effect that a great deal of superfluous work is often expended in polishing parts of the clock which have nothing to do, as indeed I have already noticed in § 181. But it requires some boldness in a clockmaker to omit these things, for nine people out of ten who go to look at a clock judge of its goodness merely by its finish (which in small work, especially watches, is generally not a bad test, by a sort of convention among the makers); and even the tenth person, though he may be aware that the going of a clock does not depend on the lacquering of the brass or the polishing of the ironwork, does not know what it really does depend upon. How many people, for instance, know whether a scape-wheel ought to be light or heavy—whether the teeth ought to fall very near the corner of the pallets, or a good way up on the dead part—whether a pendulum is better fixed close behind the pallet-arbor, or on some convenient part of the wall at the side of the clock—why some clocks will go very well with short pendulums, and others go much worse with long and heavy ones—whether cast iron cams on the great striking wheel cause more or less friction, and more or less waste of power than polished steel pins on the great wheel or on the second wheel—and why in one case cast iron wheels will act with less friction than cut brass wheels in the other case—and so forth?

There can be little doubt therefore that for obtaining a really good public clock, such as most large towns have paid for, whether they possess it or not, the only safe way is to go to some one, or at the most some three or four makers of the first reputation, and adopt the clock which is proposed by the one whom you ultimately select, either with reference to their price or other considerations. Of course the more ordinary the clock is required to be, the larger will be the number of persons competent to make it. And where tenders are obtained, from any but such a select number of makers as I have just now supposed, it is especially necessary that the advice of some competent person should be obtained either as to the conditions to be observed, or as to the character of the clocks usually made by the persons proposed to be employed, as there is always a strong family resemblance between the clocks of the same maker.

190. With regard however to testimonials respecting clocks I must caution churchwardens and others to whom they are sent, that they are (like all other testimonials nowadays) in many instances most fallacious, being frequently given by persons who have no means of ascertaining the real rate or the real value of the clocks about which they testify, and who are quite incompetent to form an accurate judgment of the construction of a clock. Two opposite instances occur to me, as illustrations of the value of testimonials of this sort. I have seen a printed testimonial about a clock, to the effect that it had not varied five minutes in several months. Now such a testimonial is not worth five farthings; for it may have meant, either that the clock had a steady gaining or losing rate of two or three seconds a day, which amounted in several months to five minutes; or that it was never more than two minutes

too slow or three minutes too fast; or (what was probably the fact) something between the two: in the first case the clock was a very good one; in the second case it was a very bad one; and in the third it may have been anything between those two extremes. On the other hand, I heard of a clergyman in London being asked the character of a clock that had been made for his church by an eminent maker, and he replied that it went very ill: this came to the ears of the person most interested in the matter, who from his own or his men's periodical observation of it thought it deserved a much better character, and he requested the clergyman to inform him by what standard of time he was in the habit of trying it; and he replied, 'by the clock of the principal church of the parish.' And it being thought by those who had made the original inquiry that the clocks of chapels of ease are not bound by ecclesiastical obedience to the mother church, and other inquiries proving satisfactory, the maker of the contumacious clock was employed upon the business in question. I can give one hint on this subject which may be useful, viz: that any testimonial about the going of a clock for so many months ought to extend from winter to summer, or it is of no real value.

191. With regard to clocks of what be called the second degree of excellence, or, as we may for convenience call them, village clocks, there is of course not quite the same necessity for caution as to the admission of candidates. At the same time nothing can be worse than the common practice of churchwardens, government offices, and public bodies, of issuing a notice that a clock is re-

quired to show time on a face of such a size, and to strike on a bell of such a weight, to go eight days, all the wheels to be of the best brass, and several other best things, and that tenders must be sent in by 12 o'clock on such a day, the only condition they seem to consider of importance. I said nothing can be worse; but I believe there is one other worse method, which I lately heard of being adopted by a certain town council, who after spending several thousand pounds on new markets, naturally thought that a small clock on the building would be useful to those who frequent it: go to some respectable maker and ask what he will make the clock for; then take his estimate about to other persons and inquire for how much less they will do it. In this way you may make sure of getting a clock 25 per cent. cheaper and 50 per cent. worse than the original estimate.

As an illustration of the results of the system of tendering without a detailed specification, I may be allowed to relate an anecdote in which I was accidentally concerned not long ago. I was staying at a place where the inhabitants were about to put up a church clock; and it being known to the clergyman that I took some interest in such things, I was requested to attend, as a sort of assessor, at a parish meeting at which the selection of the maker was to be determined. They had received six or seven tenders, varying in amount from £60 to 100 guineas; and it appeared that several of those who had sent in tenders also proposed to tender themselves to give any information that might be required by the meeting. The parishioners said they did not know what information to ask for; all the candidates offered to make the best possible clock, and several of them had sent testimonials equally good as to their capability. It appeared therefore that the only way in which I could help them was to endeavour to ascertain from the clockmakers who were in attendance what kind of clock they really intended, and were able to make. The result was (as I afterwards heard) that two of the candidates, who were prepared for an examination by the vestry, declined the examination by their assessor; and also that I had no difficulty in deciding that the intended clock of one of the two who did appear would be dear at any price, and in selecting another as competent to do the work, and intending to do it in such a manner as would be creditable to himself and satisfactory to those who had to pay for it; and he agreed to make it according to certain conditions which I was to furnish him with. I have lately had an opportunity of seeing the clock, and I was glad to find my selection justified by the result. Of course I do not mean to say that some of the other makers who sent in tenders, but did not come to the place, might not have done it just as well; but I relate this anecdote to show that out of six or seven persons who all professed to make a clock with everything of the best quality, there were at least three who were either not able or did not intend to do what they promised, and yet were just as likely in the common course of things to have been employed, as the person who was employed; in fact more likely, because his tender was very nearly the highest.

The truth is that the persons who prepare what they call the *specification* for a public clock generally do not know any more than any man in the street what they really want, or ought to want: they know the *result* they want, if they have a bell or a clock face ready made, but nothing more. And it is quite a mistake to impute dishonesty to any clockmaker, merely because he sends in either a very high tender or a very low one; for until they are examined by some competent person, there is no means of knowing whether the clock which each of them proposes is not really a fair clock to make for the money he asks; and one is just as much in conformity with the specification, which specifies nothing, as the other. And the practical result is, that the best makers will not take the trouble to tender, as they are sure to be underbid. Every now and then the architect tries his hand at the clock specification. But even architects are not omniscient. I have seen a specification—and a second *explanatory* specification too—furnished sometime ago by an eminent architect for an important public clock, which, if it had been printed instead of shown to me in manuscript, I would have copied here, not the least by way of any reflection on the gentleman who wrote it, but by way of showing how necessary it is that the public should resort to some better way of securing a good clock, than putting it into the hands of the architect.

192. Still the question remains, how are people in ordinary circumstances, who want as good a clock as possible for the money they can afford, to proceed to obtain it. If the clock is really intended to be a first-rate public timekeeper, such as all large towns ought to have, I have already mentioned what appears to be the only safe way of obtaining it. And I may add, that I believe there are few

towns in the kingdom of 10,000 people, in which there are not to be seen a number of clocks on different public buildings, which, even when they do not all set up for themselves, only keep among them a sort of conventional time, quite distinct from any of the known descriptions of time, sidereal, solar, or mean, Greenwich, or local time. And the money spent on all these bad clocks would have sufficed to procure one as good as can be made, and striking so as to be heard all over the town, and from which any number of comparatively cheap dials (or silent clocks) might be daily regulated, if necessary. Indeed it should be remembered more frequently than it is, that the *striking* of a public clock is what people really go by, and set their own clocks by. There are many places in which it would be better, both on account of the architecture of the church where the bells are, and its position, to put a striking clock without any external face (which moreover gives it considerable advantages in going) in the church, and to put a large dial in some other more conspicuous part of the town. Peterborough and Lichfield cathedrals, and several handsome churches which I could mention, are not defaced with visible dials, there being no sufficiently large space of blank wall on the bell towers on which dials could be placed. And the money that dials would cost, including the extra work they frequently require in the clock, may be much more profitably spent upon quarters, which ought to be more frequent than they are.

103. It appears to me that where the churchwardens have no better means of obtaining assistance, I may possibly make this book worth the two shillings it will cost

them, if I conclude it with some hints as to the conditions or terms which they ought to require those who send in tenders for a clock to observe or to specify; making them in fact, or such of them as may be finally adopted, a portion of the contract with the clockmaker, and also affording the means of comparing one tender with another. And the maker may be required to submit to the judgment of some person conversant with machinery, whether the conditions have been properly observed, before he is paid.

On the subject of the pendulum, and indeed on all other matters here mentioned, I must refer to my remarks in the earlier part of this chapter. As it is a mere question of money whether the pendulum should be compensated or not, the purchasers must determine it for themselves. If the pendulum is as much as 8 feet long (which nearly every place will admit of), the bob should not be less than 1½ cwt; and a 14 feet wooden pendulum may as easily have a bob of 2 or 3 cwt. as a lighter one, as there are no compensation tubes. A zinc compensation tube should be required to be made as described in § 132, at least until some method is found of rolling zinc tubes thick and solid enough for this purpose.

If the pendulum is not compensated it must be of wood, either deal or mahogany, straight in the grain, and well varnished, and of the thickness before mentioned (see § 133 and the following ones).

The escapement to be what is technically called half-dead (38), and the pin-wheel escapement (46) to be preferred.

The frame to be of cast iron, the maker to state of what thickness, and also the general construction and size of it: it being an express condition that the main body of it should never require taking to pieces for cleaning the clock when once fixed (186).

State how many days the clock is to go, and whether each train is to have three or four wheels, with reference to the circumstances mentioned in § 189, &c. In all cases a three wheeled train to be preferred, and the striking is to be from the great wheel, especially in large clocks, unless for some special reason it is impossible; and describe the cams or pins and lever arrangements.

The pallets, and all the wheels, except the great ones, in each train are to take out separately; or it will be sufficient with respect to the wheels next above the great wheels if their bushes take out so that the wheels and pivots can be cleaned.

The barrels to be of strong sheet iron brazed together, and, if possible, of such a size that all the available fall can be used for the weights hung by a double line only: if however this would make the barrels smaller than four inches in diameter for a small clock, and five for a large one, there may be three lines.*

The number of leaves in all the pinions to be stated, and of course high numbers to be preferred, except that if lantern pinions with steel pins are used, the numbers may be one-third less than those of leaved pinions. The great wheel of the going part should not have to drive fewer than 16 leaves, and the higher wheels in the train 12. If the striking is done by the second wheel, its pinion should not have less than 16 or 18 leaves; if not, 10 or even 9 leaves will do.

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* It must be remembered that the diameter of the barrels must be less than that which appears by calculation to produce a certain fall, by an amount equal to the thickness of the rope.

The size and thickness of the great wheels to be stated, and the size and number of teeth or pins of the scape-wheel. If the great wheels turn in three or four hours a foot in diameter is enough in almost any case for the going great wheel, and 1½ for the striking great wheel, each being about an inch thick. If they turn slower, they must be larger, in proportion, for large clocks.

State whether you intend to use brass or gun-metal: if brass, all the wheels to be hardened by hammering.

State what kind of maintaining power you intend to apply, the preference being given to Harrisons's going ratchett, unless the bolt and shutter is made as described in § 159.

State the size of the bevelled wheels in the leading-off work, if any; no rule can be laid down for them, but they ought to be from about five to nine inches in diameter, according to the size and number of the dials; those belonging to each dial (if more than one) need not be so thick as those that work the whole: see § 149. These wheels may be of cast iron.

All the wheels and pinions of the dial work to be of brass, to prevent rusting. In all other parts of the clock the pinions to be of steel (not iron case-hardened) (152), and the pivots also.

Describe the dial you propose, if it is not already provided; the hands to be as described in § 155.

If there are quarters on two bells, the striking wheel to be like that of the hour, with pins or cams alternately on each side; and in both parts the levers are *not* to have their axis between the striking pin and the wire (167). If the quarters are on four bells, see § 168. State whether the hour is to be let off by the quarters or the going part: the latter in very accurate clocks is the best, but requires rather more force in the going part.

The hammer-shanks and tails, and cranks, to be 18 inches long at least, where the position of the bells allow it; and as few cranks as possible to be used, and all the pivots to have brass bushes.

State the weight and rise of the hammer-head from the bell, and the weight and fall of the striking weight with which you intend to obtain that rise (165).

There must be an internal regulating dial for minutes, adjustable by some such method as described in § 150, according to the size of the clock; and either a small hand, or a visible mark on the scape-wheel with a fixed index, to examine the going of the clock, to seconds, if it is intended to be a very good one. The regulating dial to be visible (if desired) through a glass in the clock-case.

The whole to be enclosed in a wooden case, which can be opened on all sides, but locks up securely, leaving the winding holes open,* so that the clock can be wound without opening the case. The pendulum also to be enclosed, and where it is in a light place, a glass may be placed near the bottom to see the degree plate through. The weights, if required, to be boxed off for safety, and provisions to prevent accidents to be made where necessary (184).

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* In regulators (house clocks) the winding holes are frequently made in the glass, with brass caps, so that the case never requires to be opened, and moreover servants can then safely be left to wind up the clock without the possibility of their meddling with the hands.

On the other hand, the clockmaker may fairly demand, in order that justice may be done to his clock when it is made, that the chamber in which it stands shall if possible be made so light that a candle shall never be required to examine the clock in the day time; otherwise the clock will never be properly cleaned.

And it is equally due to the maker of a good clock, as well as for the interest of those to whom the clock belongs, that a competent person should be employed to examine and clean it periodically; who will probably *not* be the person who undertakes to do it for the least money. Some of the readers of this book will know of a town which had to pay rather dearly for putting its church clock into the hands of a cheap and ignorant contractor; for having to do something to the hammer, he left it striking with its edge instead of its face, and thereby cracked a very fine bell of 30 cwt.

I do not propose the above conditions as perfect, or as necessary to be imposed upon clockmakers who from their known character can be trusted to do without. But I believe that few such clockmakers would desire to make any material alteration in them, as they by no means restrict them to any particular pattern of clock, and are in a great measure adopted from the practice of the best makers. And I have no doubt that such makers would rejoice to see some such test applied to themselves and their competitors, as it would certainly tend to exclude from our churches and public buildings many pieces of machinery, which not only are a disgrace to them, but also discourage all attempts to improve the art; since no one will go on spending his time and money in contriving and making improved machines which are to be rejected for old fashioned and good for nothing articles made at somewhat smaller cost.

I shall be glad if this, the only English book on the construction of Public Clocks, does anything towards raising the character of a machine, which, notwithstanding its general and important uses, has been strangely left behind in the progress of mechanical improvement; and which, not only in its history but in its own duration, connects the present with the past more than any other instrument in use: a machine of which it has been happily said,* 'there is no dead thing so like a living thing as a clock:' deliberately performing its appointed work by day and by night, with scarcely any interruption during the lapse of many generations of men, reminding them all of their own passing away, and of the period when 'the great clock of Time will have run down for ever.'

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* In "The Old Church Clock," by the Rev. R. Parkinson, Canon of Manchester, a pleasing little book, but not on clockmaking.

THE END.

[illegible], PRINTER, HART STREET, BLOOMSBURY.

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